Intelligent Adaptive Systems

Literature-Research of Design Guidance for Intelligent Adaptive Automation and Interfaces

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Abstract

Human-machine system performance can be improved by using technologies that intelligently adapt the operator machine interface (OMI) or by task automation provided to the operator with external context (i.e., task environment) and internal context (i.e., operator state). It is challenging to design effective Intelligent Adaptive Systems (IAIs) due to a lack of established design guidelines. A literature review was conducted to examine approaches to the design of IASs, and a framework was developed to describe these design approaches using consistent and unambiguous terminology. Combining methodologies from both Human Computer Interaction (HCI) and Human Factors (HF) fields, conceptual and design frameworks were developed to provide the design and implementation of IASs. Finally, a number of decision trees (see section 12) were used to select appropriate analytical techniques and design approaches. The proposed frameworks provide guidelines for designing IASs in the military domain, and broadly guide the design of generic systems to optimize human-machine system performance.

Systèmes adaptatifs intelligents

Revue de la documentation relative à l'orientation de la conception de l'automatisation et des interfaces adaptatives intelligentes

Résumé

Il est possible d'améliorer considérablement les performances des ensembles homme-machine en ayant recours à des technologies qui peuvent adapter intelligemment l'interface opérateur-machine (IOM) et/ou l'automatisation des tâches et le soutien accordé à l'opérateur conformément au contexte externe (c.-à-d. le contexte de la tâche) et au contexte interne (c.-à-d. l'état de l'opérateur). Toutefois, l'absence de lignes directrices établies en matière de conception constitue un lourd obstacle à la conception efficiente de systèmes adaptatifs intelligents (SAI). Un examen approfondi de la documentation a été effectué afin d'examiner les démarches actuelles en conception des SAI et un cadre de travail unifié a été élaboré afin de décrire des perspectives conceptuelles en faisant appel à une terminologie uniforme et non ambigüe. Par ailleurs, en combinant des méthodes de conception des domaines des interactions homme-ordinateur (IHO) et des facteurs humains (FH), nous avons élaboré des cadres conceptuels et de design afin d'élaborer des lignes d'orientation afin d'aider à la conception et à la mise en oeuvre de SAI. Un certain nombre de critères de sélection des méthodes analytiques et conceptuelles appropriées ont aussi été développés. Les cadres recommandés ne guideront pas seulement la conception des SAI dans les domaines militaires, ils aideront aussi dans le domaine des systèmes civils afin d'optimiser les performances des systèmes homme-machine.

Executive Summary

Human-machine system performance can be improved by utilising technologies that intelligently adapt the operator machine interface (OMI) or by task automation and support provided to the operator with external context (i.e., task environment) and internal context (i.e., operator state). It is challenging to design effective Intelligent Adaptive Systems (IASs) due to a lack of established design guidelines. Intelligent Adaptive Systems assist operators with mental and physical activities such as decision support systems, automation, expert systems, and information fusion. IAS provides varying degrees of autonomy; they can be used as a tools, aids, associates, or autonomous agents. IAS act as assistants, associates or coaches, providing different levels of sophistication. In addition, a lack of integration between the Human Computer Interaction (HCI) and Human Factors (HF) communities has allowed terminology to become ambiguous and misleading when applied globally. There is a pressing need to develop a framework to describe these approaches using consistent and unambiguous terminology. There is a paucity of established design guidelines for the development of advanced operator machine interfaces to support operators in dynamic, error-critical, and information-rich domains.

The goal of this literature search was to provide support to establish design guidelines for IASs through the review of frameworks, analysis tools and processes for IASs, and through the provision of general design recommendations and guidelines for the development of IASs, with particular emphasis on the OMI. This work was completed under contract W7711-067983, to DRDC Toronto.

Relevant literature was collected from scientific, defence, government, and internet-based sources pertaining to IASs. All articles were classified in terms of Level of Experimentation, Peer Review, Domain Relevance and Literature Review Area. The literature was collated and reduced according to selection criteria. Each article was evaluated according to: the degree of peer review (e.g., technical report, conference proceedings, journal article), degree of experimentation involved (e.g., conceptual study involving no experimentation, laboratory-based experimentation, field-based studies), and proximity to military domains. Each article was earmarked for inclusion into or exclusion from the final review.

After reviewing the approaches concerned with the design of an intelligent adaptive system, a generic conceptual architecture was developed. This architecture has not been validated as of yet and has the following four components, which are common to all developed and developing IASs:

- *Situation Assessment and Support System*. Involves functionality relating to real-time mission analysis, automation, and decision support. Monitors and tracks the current mission state and aircraft/vehicle/system status (e.g., heading, altitude, threats etc.) using extensive a priori task, goal, tactical, operational, and situational knowledge. Overall, this provides information about the state of the aircraft/vehicle/system within the context of a specific mission, and uses a knowledge-based system to provide assistance (e.g., automate tasks) and support to the operator.

- *Operator State Assessment*. Consists of functionality relating to real-time analysis of the psychological, physiological and/or behavioural state of the operator. Primary

functions may include continuous monitoring of workload, inferences about current attention focus, ongoing cognition (e.g., visual and verbal processing load), and intentions using extensive a priori operator knowledge (e.g., models of human cognition, control abilities. and communication). The system is also able to monitor the operator for dangerously high and low levels of arousal. Overall, this provides information about the objective and subjective state of the operator within the context of a specific mission. This information is used to optimize operator performance and safety, and provides a basis for the implementation of pilot assistance and support.

- *Adaptation Engine*. Uses the higher-order outputs from Operator State Assessment and Situation Assessment systems, as well as other relevant aircraft/vehicle/system data sources, to increase the quality of the match between aircraft/vehicle/system state, operator state, and the tactical assessments provided by the Situation Assessment system. These integrative functions (operator and environmental state) require that the system be able to influence the prioritization of tasks (i.e., intelligent adaptive automation) and/or determine the means by which information is presented to the operator (i.e., intelligent adaptive interface).
- *Operator Machine Interface.* The means by which the operator interacts with the aircraft/vehicle/system in order to fulfil mission tasks and goals. This is also the means by which, the operator interacts with an intelligent adaptive system (e.g., a tasking interface manager). The design of the OMI, is defined by existing HF and HCI best-practice and standards.

All four components operate within the context of a closed-loop system: a feedback loop re-samples operator state and situation assessment following the adaptation of the OMI or automation. The goal is to adjust the level of adaptation so that optimal operator states (e.g., performance, workload etc) are attained and maintained.

The literature research achieved the following goals:

- Identified the advantages, disadvantages and applicability of development frameworks, analysis methodologies, design approaches, and operator-state monitoring approaches;
- Make some progress in unifying independent HF and HCI approaches to the development of IASs by providing a generic framework that maps to both approaches by focusing on system functionality and capability; and,
- Integrate design methodologies from both HCI and HF fields and develop guidance for developers to assist in the design, development and implementation of IASs, with emphasis on development of the OMI. A number of criteria for the selection of appropriate analytical and design approaches were also recommended.

The proposed frameworks will not only provide guidance for designing IASs in military domains, but will also guide other civilian systems to optimize human-machine system performance.

Systèmes adaptatifs intelligents

Revue de la documentation relative à l'orientation de la conception de l'automatisation et des interfaces adaptatives intelligentes

SOMMAIRE

Il est possible d'améliorer considérablement les performances des ensembles homme-machine en ayant recours à des technologies qui peuvent adapter intelligemment l'interface opérateur-machine (IOM) et/ou l'automatisation des tâches et le soutien accordé à l'opérateur conformément au contexte externe (c.-à-d. le contexte de la tâche) et au contexte interne (c.-à-d. l'état de l'opérateur). Toutefois, l'absence de lignes directrices établies en matière de conception constitue un lourd défi à la conception efficiente de systèmes adaptatifs intelligents (SAI). Ces systèmes aident les opérateurs pour une multitude d'activités mentales et physiques (p. ex. les systèmes d'aide à la décision, l'automatisation, les systèmes experts et la fusion d'information), avec divers degrés d'autonomie (p. ex., outils, aides, associés, agents autonomes) et de perfectionnement (p. ex., assistant, associé ou conseiller). En outre, l'intégration insuffisante des collectivités s'intéressant aux interactions homme-machine (IHO) et aux facteurs humains (HF) a favorisé le développement de terminologies de plus en plus ambigües, ou même trompeuses, lorsqu'elles sont appliquées de manière générale. Il devient donc pressant de développer un cadre de travail unifié afin de décrire des perspectives conceptuelles en faisant appel à une terminologie uniforme et non ambigüe. Par ailleurs, il n'y a pas de lignes directrices établies en matière de conception pour le développement d'interfaces opérateur–machine avancées afin d'aider les opérateurs dans les domaines dynamiques, propices à l'occurrence d'erreurs critiques et riches en information.

L'objectif de cette revue de la documentation consistait à apporter un soutien à l'établissement de lignes directrices pour la conception de systèmes adaptatifs intelligents en étudiant les cadres de travail, les outils et processus d'analyse servant les SAI, et en élaborant des recommandations et lignes directrices générales pour la conception et le développement de SAI, avec une insistance particulière sur les IOM. Ce travail a été effectué dans le cadre d'un contrat conclu avec RDDC Toronto.

La documentation pertinente a été recueillie à partir de sources scientifiques, de la défense, du gouvernement et d'Internet portant sur les SAI. Tous les articles ont été classés en fonction du niveau d'expérimentation, de l'examen par les pairs, de la pertinence au domaine et du domaine d'examen de la documentation. La documentation a été colligée et réduite en fonction de critères de sélection appropriés. Chaque article a été évalué en fonction du degré d'examen par les pairs (p. ex., rapport technique, actes de conférence, articles de journaux), du degré d'expérimentation réalisée (p. ex., étude conceptuelle n'impliquant aucune expérimentation, expérimentation en laboratoire, études sur le terrain) et proximité des

domaines militaires. Chaque article a aussi été classé en conséquence en vue d'être inclus dans le processus d'examen final, ou exclus de ce processus.

Après avoir examiner les démarches visant le développement d'un système adaptatif intelligent, nous avons élaboré une architecture conceptuelle générique. Cette dernière se compose de quatre modules communs à tous les SAI développés et en voie de développement :

- *Système d'évaluation et de soutien de la situation*. Cet élément comporte des fonctionnalités liées à l'analyse de mission, à l'automatisation et à la prise de décision en temps réel. Ce système effectue la surveillance et le suivi de l'état d'une mission en cours et l'état des aéronefs, véhicules ou systèmes (p. ex., cap, altitude, menaces, etc.) en faisant appel à des connaissances préalables étendues des tâches et objectifs, ainsi que des aspects tactiques, opérationnels et situationnels. Dans l'ensemble, tout cela fournit de l'information au sujet de l'état objectif des aéronefs, véhicules ou systèmes dans le contexte d'une mission spécifique et il fait appel à un système à base de connaissances pour prêter assistance (p. ex., en automatisant des tâches) et prêter appui à l'opérateur.
- *Évaluation de l'état de l'opérateur*. Cet élément comporte des fonctionnalités liées à l'analyse en temps réel de l'état psychologique, physiologique et/ou comportemental de l'opérateur. Les principales fonctions peuvent comprendre la surveillance en continu de la charge de travail, des inférences au sujet de la concentration, des connaissances perceptuelles (p. ex., charge de traitement visuelle et verbale) et des intentions en faisant appel à des connaissances préalables de l'opérateur (p. ex., modèles cognitifs humains, habilités de commande et communication). Ce système est aussi en mesure de surveiller l'opérateur pour détecter les niveaux dangereusement élevés ou bas d'éveil. Dans l'ensemble, cela fournit de l'information au sujet de l'état subjectif et objectif de l'opérateur dans le contexte d'une mission spécifique. Cette information est utilisée afin d'optimiser le rendement et la sécurité de l'opérateur, et cela fournit une base pour la mise en oeuvre de systèmes d'aide et de soutien des pilotes.
- *Moteur adaptatif*. Il fait appel aux extrants de niveau élevé du module d'évaluation d'état de l'opérateur et d'évaluation et de soutien de la situation, ainsi que d'autres sources de données pertinentes des aéronefs/véhicules/systèmes afin de maximiser la correspondance entre l'état des aéronefs/véhicules/systèmes, l'état de l'opérateur et les évaluations tactiques fournies par le système d'évaluation de la situation. Ces fonctions intégratives exigent que le système soit capable d'influer sur la priorisation et l'affectation des tâches (c.-à-d. l'automatisation adaptative intelligente) et/ou de déterminer les moyens de présentation de l'information à l'opérateur (ce qui correspond à l'interface adaptative intelligente).

- *Interface opérateur-machine.* C'est le dispositif qui permet à l'opérateur d'interagir avec les aéronefs/véhicules/systèmes afin de satisfaire les tâches et objectifs d'une mission. Il s'agit aussi d'un moyen qui permet, le cas échéant, à l'opérateur d'interagir avec le système adaptatif intelligent (p. ex., un gestionnaire d'interface d'attribution de tâche). La conception de l'IOM, ainsi que son automatisation, sont définies par les pratiques exemplaires et normes reconnues dans le domaine des FH et des IHO.

Les quatre modules fonctionnent dans une structure à boucle fermée : une boucle de réaction échantillonne l'état de l'opérateur et l'évaluation de la situation après l'adaptation de l'IOM et/ou l'automatisation. Ce processus a pour objectif d'ajuster le niveau d'adaptation afin que des niveaux optimaux puissent être atteints et maintenus pour l'opérateur (p. ex., sur le plan des performances, de la charge de travail, et ainsi de suite).

L'examen de la documentation a permis d'atteindre les résultats suivants :

- Relever les avantages et désavantages et établir l'applicabilité des cadres de développement, des méthodes d'analyse et de conception, ainsi que les méthodes de surveillance de l'état;
- Progresser dans l'unification des approches jusqu'à présent indépendant en matière de facteurs humains et d'IHO pour le développement de SAI en fournissant une architecture conceptuelle générique qui correspondrait aux deux approches en se concentrant sur les fonctionnalités et capacités;
- Intégrer des méthodes de conception des domaines des IHO et des facteurs humains et élaborer des lignes d'orientation à l'intention des développeurs afin d'aider à la conception, au développement et à la mise en oeuvre de SAI, en mettant un accent particulier sur le développement des IOM. Un certain nombre de critères de sélection des méthodes analytiques et conceptuelles appropriées ont aussi été recommandés.

Les cadres recommandés ne guideront pas seulement la conception des SAI dans les domaines militaires, ils aideront aussi dans le domaine des systèmes civils afin d'optimiser les performances des systèmes homme-machine.

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1 Introduction

The Department of National Defence, Defence Research and Development Canada (DRDC), Toronto, Ontario, has started a research project to examine the application of theoretical approaches to the design of intelligent and/or adaptive interfaces and to develop design recommendations that maximize overall human-machine system performance. Currently, there are few established design guidelines for advanced operator interfaces that provide assistance to decision makers who need to manage the vast amounts of data and information in a complex and networked environment. DRDC Toronto has completed a project focussing on the design and development of intelligent adaptive interfaces (IAI) in the context of controlling multiple Uninhabited Aerial Vehicles (UAVs). The aim of this UAV IAI project was to develop operator interface design guidelines to support reduced manning and enhanced performance in complex military systems. Within this project, theoretical frameworks and design concepts for designing an agent-based system were developed. Under this theoretical guidance, hierarchical goal analysis and performance modelling were conducted to compare overall system performance while controlling multiple UAVs with and without the aid of automation agents. Preliminary design guidelines were identified.

The goal of this literature review is to provide support to establish design guidelines for Intelligent Adaptive Systems (IASs) through the review of frameworks, analysis tools and processes for IASs, and through the provision of general design recommendations and guidelines for the development of IASs, with particular emphasis on the Operator Machine Interface (OMI). This work was completed under contract W7711-067983, to DRDC Toronto.

1.1 Intelligent Adaptive Systems: Automation and Interface

Modern technology is very complex; this allows vast amounts of data to be available to operators from many sources. Considerable computerized assistance is needed for operators to be able to integrate and act upon the data. However, perceiving and interpreting all of the relevant information and choosing an appropriate response within the temporal constraints of the situation would challenge any intelligent agent, human or machine (Banbury, Bonner, Dickson, Howells and Taylor, 1999).

Traditionally, there have been two main thrusts of research and development undertaken to address problems associated with operators working under conditions of excessive workload levels (e.g., sub-optimal task performance, error, loss of Situation Awareness [SA], etc.). The first approach originated from the Human Factors (HF) community, in which research was conducted to study the effects of adaptable automation[1] on operator performance and workload within error-critical domains, such as aviation and industrial process control. The second approach originated from the Human Computer Interaction (HCI) community, in

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[1] *Automation:* The mechanisation and integration of the sensing of environmental variables; machine data processing and decision making; machine mechanical action; and, machine information action/communication (Sheridan and Parasuraman, 2006).

which research was conducted to study the effects of adaptable operator machine interfaces[2] on operator performance within relatively more benign domains, such as word processing and web browsing.

Adaptable automation and OMIs address very similar issues; both adaptable automation and OMIs seek to reduce operator workload, and in doing so, facilitate more efficient task performance by replacing or augmenting the human operator. In addition, both rely on a user model to adapt the system to pre-defined operator characteristics (e.g., workload, task performance and progress, and so on) according to the status of a task model (e.g., required tasks/goals). Intelligent Adaptive Systems, therefore, seek to enhance human-machine system performance by utilising technologies that can intelligently adapt the OMI and/or task automation and support provided to the operator in accordance with the both the external context (i.e., task environment) and internal context (i.e., operator state). The human operator is an intrinsic part of the IAS, given the closed-loop nature of IASs (e.g., monitoring and adapting to operator state changes the nature of how tasks are performed, which in turn requires re-sampling of operator state),. The terminology used in this report should therefore be defined at the outset: *human* refers to the operator, *machine* refers to the device used to perform a task or assist the operator perform the task, and *system* refers to the synergy of the two.

Despite the obvious similarity between the HF and HCI research in intelligent adaptive systems, there is little research that integrates these two research streams. This is an unfortunate oversight by the HF and HCI communities as insufficient integration between HF and HCI could increase the potential for confusion in terminology. For example, many of the intelligent adaptive automation systems in development involve some degree of OMI adaptation (e.g., the Tasking Interface Manager of the Cognitive Cockpit; see Section 10.2.3). However, this research has not drawn upon the findings from the HCI research studies on adaptable OMIs, primarily since the HCI field has concentrated, almost exclusively, on computing applications, such as word-processing and web-browsing. Similarly, key studies from the HF community are rarely cited by the HCI community (see Section 6.4.3). Thus, the terminology used by both fields to describe identical systems is different. The remainder of this section focuses on briefly identifying similarities between the HF and HCI approaches, and developing consistent terminology that describes the *functions* and *capabilities* of IASs that map to both HF and HCI approaches.

Figure 1 draws parallels between the historical origins of the development of Intelligent Adaptive Interfaces within the HCI community and Intelligent Adaptive Automation (IAA) within the HF community, resulting in Intelligent Adaptive Hybrid (IAH) systems. This reflects the use of both adaptable automation and an adaptable interface within the same system. Each system will be considered as IASs (depicted by the blue shaded area) and will be reviewed within this report. The technologies described in Figure 1 are not intended to represent discrete stages in development, but instead, represent steps upon a continuum of intelligent adaptive system development.

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[2] *Operator Machine Interface:* The aggregate of means by which the human operator interacts with the machine. The OMI provides the means of input (i.e., allowing the operator to manipulate the machine) and output (i.e., allowing the machine to produce the effects of the operator's manipulation).

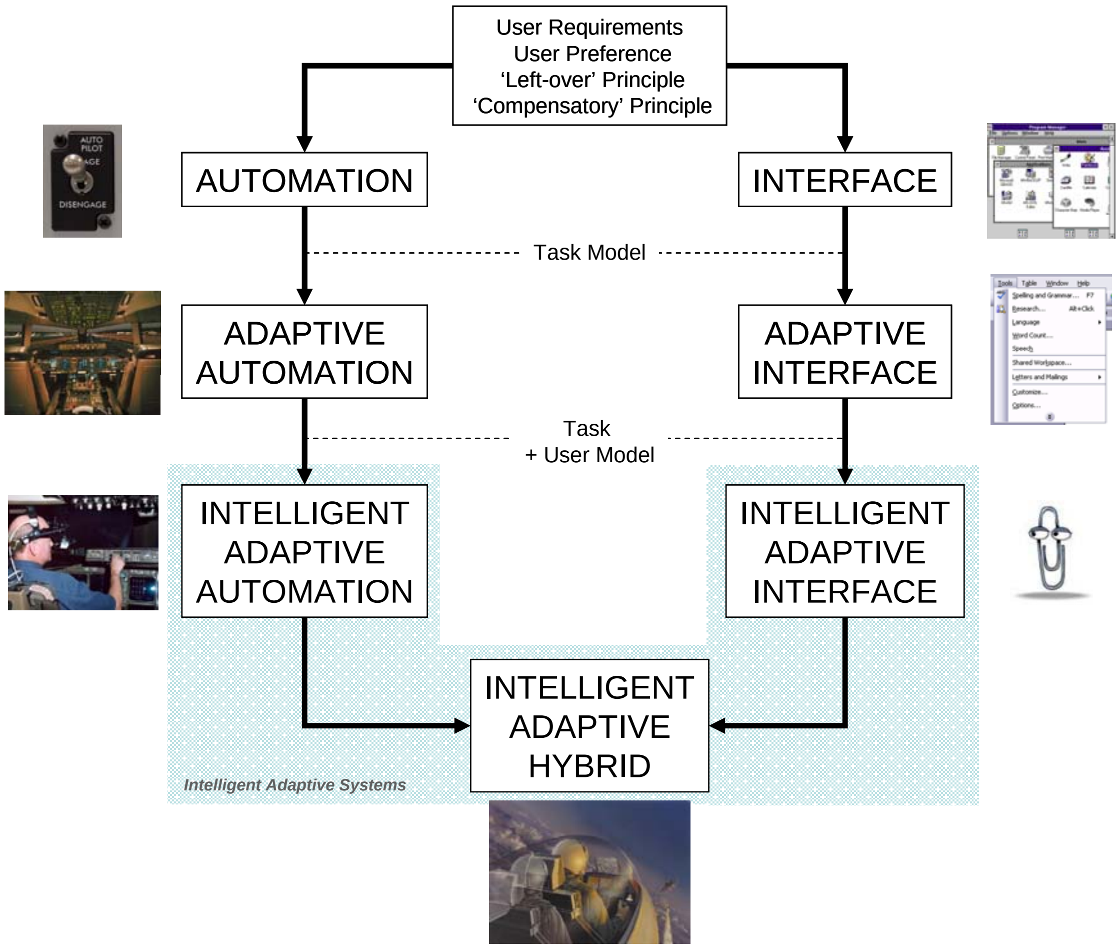


Figure 1: Illustration of the parallel development of Intelligent Adaptive Systems from the HCI and HF communities.

Conventional *Automation* (i.e., the replacement or augmentation of human work with mechanical or electronic machines, such as an autopilot) and the conventional operator-machine *Interface* (i.e., a common boundary shared by a human operator and a machine, across which data or information flows, such as a Windows-based display) are both designed using a combination of user requirements (i.e., functionality and capability required to perform a given task), and user preferences (i.e., functionality and capability that is not necessarily required to perform a give task, but nonetheless improves the perceived quality of the operator's interaction with the machine). In addition, automation capability is also based on the 'left-over' principle: operators are left with functions that have not been automated or could not be automated, and the 'compensatory' principle: functions are allocated according to the strengths and weaknesses of the human and the machine (e.g., Fitts, 1951).

The progression from conventional automation and interfaces to *Adaptive Automation* and *Adaptive Interfaces* is possible through the use of a *Task Model* (i.e., the system's information of the task activities that are likely to be conducted by the operator). Similarly, the progression from these systems to *Intelligent Adaptive Automation* and *Intelligent Adaptive Interfaces* is possible through the use of a *User Model* (i.e., the system's knowledge of the capabilities, limitations and knowledge of the human operator), in addition to the task model. Finally, the combination of automation and interface adaptation, *Intelligent Adaptive Hybrid* systems, is depicted as the confluence of the two research streams. Sections 6.2, 6.3 and 6.4 describe each of these seven technologies in more detail.

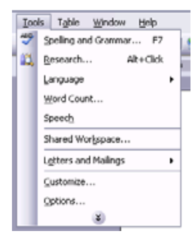
1.2 Origins of Intelligent Adaptive Interfaces

Operator machine interface technologies exist in a number of guises, from conventional interfaces, to adaptive interfaces, and finally to intelligent adaptive interfaces. Sections 6.2.1 through 6.2.3 describe the evolution of intelligent adaptive interfaces.

1.2.1 Conventional (Operator-Machine) Interfaces

In their most general form, conventional operator-machine interfaces are the medium that supports operator interaction with a particular machine, device, computer program or other complex tool. The OMI facilitates input, allowing the operator to manipulate a system, and output, allowing the machine to produce the effects of the operator's manipulation.

1.2.2 Adaptive Interfaces



Adaptive interfaces enhance operator interaction with a system by making the system more efficient, effective and easy to use. The interface is adapted (e.g., menu content) with the aim of matching its content to changing task-related circumstances (e.g., according to the mode selected, application used, etc.). The system controls the adaptation of the interface, and how it occurs, along with the amount of adaptation that occurs; although, the operator has some control over how the system adaptation is configured initially.

1.2.3 Intelligent Adaptive Interfaces

Intelligent Adaptive Interfaces are OMIs that change their control and/or display characteristics to react to task and/or operator states in real-time (Hou, 2007). Intelligent Adaptive Interfaces are epitomised by Microsoft's Office Assistant. This feature was included in Microsoft Office 97 and subsequent versions until Office 2007. The most 'popular' Office Assistant was named "Clippy" after its default animated paperclip representation. This feature was an entry point to the application's help system, presenting various help search functions and offering advice based on Bayesian algorithms. Clippy would open when the program thought the operator required assistance, and would modify the formatting of the document and content of the menus accordingly. For example, typing an address followed by "Dear" would prompt Clippy to open and state "It looks like you're writing a letter. Would you like help?". The algorithms would use a combination of task-based (e.g., how a letter is usually formatted) and user-based (e.g., how many mistakes the operator has made trying to write a letter) models to modify the interface to match the operator's needs and requirements.

Similar to adaptive interfaces, the amount of adaptation that occurs is controlled entirely by the system, although the operator has some control over how the system adaptation is configured initially (e.g., the user is capable of turning off Clippy). Intelligent Adaptive Interface systems are reviewed in Section 8.2 of this report.

1.3 Origins of Intelligent Adaptive Automation

The advent of automation technology has created the opportunity to decrease the tasks operators perform and assist them in making tactical and strategic decisions. While conventional automation has often been designed to replace human control and decision making, intelligent aiding seeks to augment and enhance human judgment and responsibility. Sections 6.3.1, 6.3.2, and 6.3.3 describe the evolution of intelligent adaptive automation.

1.3.1 Conventional (Static) Automation

The general intention of conventional, or static, automation is to increase safety and efficiency by moderating operator workload. Advances in automation technology have facilitated a wide variety of tasks to be completed under automatic control, such as flight controls, navigation systems, and system health checks. The conventional approach to automation sought to replace operator involvement in certain tasks with automated systems. As technology advanced, more functions were considered for automation; the general principle was that if an automated system could surpass human performance, the function was allocated to the system. This approach is also referred to as static automation. The system designer initiates an allocation of function between the operator and the automated system (i.e., the agent in control is fixed for the duration of the task). The level of automation is not context dependent and therefore is not sensitive to the external situation.

The allocation of tasks between operator and machine can range from full automation to full operator control. Task allocation depends on system measures and task efficiency, rather than on satisfying the needs of the human operator. For example, Fitts (1951) created a set of criteria where the human can exceed machine capability (e.g., the ability to improvise and use flexible procedures, and the ability to reason inductively), and where the machine can surpass human capability (e.g., the ability to perform repetitive and routine tasks)

However, such fixed allocation of function has a tendency to ignore the fundamental question: how do changes to the allocation of tasks affect operator performance? Effects on the cognitive abilities and deficiencies of the operator (e.g., motivation, tension, boredom and fatigue) are of paramount importance to the safe operation of the overall human-in-the-loop system. For example, whilst the machine can outperform an operator on most monitoring tasks, the human excels in the ability to adapt when situations change.

There are concerns that this traditional approach has not been entirely successful and that increased automation may make an operator’s task more difficult. Much research (see section 10.1.1) has demonstrated problems associated with conventional automation in aviation, including: increased monitoring load; out-of-the-loop performance problems; loss of skills; complacency; lack of trust (i.e., scepticism); and increased system complexity. Challenges for operators using conventional automation can be, maintaining direct involvement in the task and interpreting large amounts of information. This can result in a shift from an operator being a hands-on controller, towards the role of a being system manager and system monitor. This is an unfortunate development considering that humans are not reliable monitors. Humans may experience difficulty maintaining alertness and vigilance over time without active involvement in the system's operation.

1.3.2 Adaptive Automation

The desire to improve the relation, and therefore performance, between human and machine has prompted the development of an alternative approach to automation. Adaptive automation is described as 'adaptive' because the control of the commencement and the ending of specific tasks are shared between the operator and the machine. Adaptive automation is required to minimise the negative effects of static allocation (e.g., skill degradation and reduction of situation awareness), while simultaneously achieving optimal levels of system performance. An example of a simplistic adaptive automation system is a modern flight management system that automates the presentation and partial completion of operating checklists according to the phase of flight, or the detection of sub-system failures (i.e., using a task model). More complex forms of adaptive automation utilise simplistic user models (e.g., simple behavioural indices of high workload) as a mechanism to control the onset and offset of automation.

Adaptive automation represents an alternative design approach to the implementation of automation in that the relationship between machine and operator is flexible and context dependent. The provision of adaptive machine aiding is not pre-determined at the design stage. The task allocation to the human or system is not fixed. An adaptive automation system is dynamic in nature in that the loci of control, the control function within a system, are constantly changing.

Adaptive automation seeks to take advantage of the differences between the abilities of humans and machines through a strategy that allows changes in task allocation. An example of a strategy for adaptive task allocation would be operator workload levels. Emphasis is given to the prevention of task over-load (or under-load) imposed on the operator, at defined point(s) along a continuum.

Adaptive automation occurs when the control decisions concerning the onset, offset, and degree of automation are shared between the operator and machine. Within such a system, the human operator remains 'in-the-loop' and the automation intervenes only when an increase (or decrease) in operator workload requires system support to meet operational requirements. In providing this dynamic or adaptive support, the perceived loss of control associated with static automation can be reduced.

Studies have shown (Hilburn, Molloy, Wong & Parasuraman, 1993; Parasuraman, Mololoua, Molly & Hilburn, 1993; Riley & Parasuraman, 1997) that the detection of automation failures is substantially degraded in systems with conventional automation in which the allocation of tasks between operator and system remains fixed over time (see section 10.1.1). When using an adaptive automation system, brief periods of manual task allocation increases the detection rate of automation failures (Hilburn et al. 1993, Parasuraman et al. 1993). Adaptive automation improved monitoring performance over relatively long periods of time. However, adaptive automation introduces complexity during task allocation that can result in new problems of awareness of system functional state and automation failure detection. A key design issue is optimising triggering conditions for task re-allocation (e.g., by monitoring operator behaviour or situation/task events; see Section 8.5.1.1).

Several studies have compared adaptive to conventional automation, or manual control. They have shown that the introduction of adaptive automation systems has met with some success. These results can be summarised as follows:

- Reductions in response time to flight management task demands of up to 40% (Chu and Rouse, 1979);
- Reductions in time to place sensors in anti-submarine warfare of 15% (Freedy, Madni and Samet, 1985);
- Increases of 5–9% in tracking performance together with increases of up to 25% in identification performance in an aerial reconnaissance task (Morris and Rouse, 1986); and,
- Increases of up to 25% in tracking performance together with increases of up to 42% in target identification in a reconnaissance task (Forester, 1986).

1.3.3 Intelligent Adaptive Automation

Traditionally, automation design decisions have focused on optimising the performance of the technology (i.e., technology-centred). IAA is human-centred; IAA design is based on a consideration of human limitations and capabilities, rather than of system and mission performance. IAA systems rely heavily on detailed and comprehensive user models (e.g., models of human cognition, knowledge of human capabilities and limitations). These systems seek to restore the pilot to the role of the decision-maker, while at the same time providing safeguards for situations in which time limitations, or the complexity of the problem, restrict operator problem solving ability.

Intelligent Adaptive Automation seeks to augment and enhance an operator’s judgement and responsibility, while mitigating the operator’s limitations. These systems can be considered to be ‘intelligent’ insofar as they exhibit behaviours that are consistent with intelligent human-like characteristics (Taylor and Reising, 1998, 1999), such as:

- Active collection of information;
- Goal driven;
- Capable of reasoning at multiple levels; and,
- Capable of learning from experience.

Functional integration, rather than function allocation, is an important characteristic of IAA systems (Geddes, 1997). As tasks become more mental than physical, the validity of applying the concept of functional separation of tasks is debatable. With functional integration, behaviours required by the domain are shared across the functional components, including the operator. The same behaviour can be performed by several functional components, rather than just one, providing more robust and flexible integrated systems than systems in which functions are allocated to specific system components.

Previous attempts and ongoing development of Intelligent Adaptive Automation systems can be distinguished in terms of the tasks and roles that they perform (Geddes and Shalin, 1997):

- *Assistant*. Performs specific tasks when instructed by the operator, using basic task and situation knowledge. For example, a system could provide a pilot with an assessment of a threatening aircraft when asked.
- *Associate*. Automatically recognises that the operator requires assistance (using complex task and situation knowledge, and basic user knowledge), and provides some level of support. For example, a system could recognise a threatening situation and automatically provide the pilot with all threat information.
- *Coach*. Using complex task, situation and user knowledge, these types of systems are capable of recognising the need for automation in order to achieve a mission objective, and providing instructions to the operator on how to achieve the objective. For example, the pilot is presented with the most threatening aircraft first, in accordance with the higher-level goal of maximising own-ship survivability.

Intelligent Adaptive Automation systems are reviewed in Section 8.3.

1.4 Intelligent Adaptive Hybrid Systems

Intelligent Adaptive Hybrid systems are a combination of IAA and IAI technologies that are capable of context-sensitive communication with the operator. IAH systems technologies currently under construction operate at the level of Assistant (e.g., Germany's Cockpit Assistant System [CASSY]/ Crew Assistant Military Aircraft [CAMMA] programmes, France's Co-pilote Electronique programme), Associate (e.g., USAF Pilots' Associate (PA) programme and US Army Rotorcraft Pilots' Associate (RPA) programme), and Coach (e.g., the United Kingdom's Cognitive Cockpit programme).

Technological advances in both Artificial Intelligence (AI) and the physiological monitoring of human performance may allow higher levels of intelligent support to be realised. It is believed that in the future, IAH systems will be considered more as fully integrated, intelligent systems that can adopt agent-like properties, rather than as conventional systems with a discrete (i.e., independent) automation control centre. Future IAH systems will be able to (Eggleston, 1997):

- Respond intelligently to operator commands, and provide pertinent information to operator requests;
- Provide knowledge-based state assessments;
- Provide execution assistance when authorised;
- Engage in dialogue with the operator, either explicitly or implicitly; and,

- Provide the operator with a more useable and non-intrusive interface by managing the presentation of information in a manner appropriate to the content of the mission.

Furthermore, IAH systems will be able to provide support for the basic functions of assessment, planning, co-ordinating and acting. In these cases, an IAH system can propose a candidate solution for the human, or in the extreme, propose, select and execute the solution for the human. IAH systems will provide several of the following functional capabilities:

- *Situation Assessment*. This functional capability supports the organisation of large amounts of dynamic data into concepts at varying levels of aggregation and abstraction. Situation assessment includes task, system and world models (refer to Figure 17). It provides the context in which the aiding system is operating and gives this information to other software processes and to the human user;

- *Planning*. Based on the situation determined by the Situation Assessment, plans are formulated by the aiding system. The plans may cover different periods of time at different levels of abstraction. With information from the user and environment, aiding systems can independently formulate and propose plans to the human users, and can complete the details of partial plans provided by the operators;

- *Acting*. An intelligent aiding system is not necessarily a passive system, but may have the capability to act on behalf of its human operators. Given a set of plans and an evolving situation, the intelligent aiding system may issue commands directly to the active elements of the system, such as sensors, communications, propulsion, flight controls and secondary support systems; and,

- *Co-ordination of Behaviours*. An intelligent aiding system must also be able to co-ordinate its behaviours at four distinct levels. At the lowest level, the intelligent aiding system must co-ordinate between its own assessment, planning and executing processes to produce coherent behaviours. It must co-ordinate with the operators at the planning level to receive direction and provide useful recommendations. It must co-ordinate with the operator at the action level so that the operator and the aid can act in concert. The intelligent aid must co-ordinate with the other independent participants to avoid undesirable conflicts and to satisfy the requirements of higher level goals.

Intelligent Adaptive Hybrid systems are reviewed in Section 8.4.

1.5 A Conceptual Framework for Intelligent Adaptive Systems

Computer based systems assist the operator in a multitude of mental and physical activities such as, decision support systems, decision aids, automation, adaptive automation, intelligent automation, intelligent adaptive interfaces, expert systems, knowledge-based systems, data fusion, and information fusion. Computer based systems also have varying degrees of autonomy (tool, aid, associate autonomous agent) and sophistication (assistant, associate or coach). There is a need to develop a unified framework to describe these conceptual approaches using consistent and unambiguous terminology.

The next section re-defines the problem space by developing a framework which encompasses both HF and HCI approaches. The framework defines IASs as multi-dimensional, continuum-based and dynamic. The dimensions upon which all IASs, in terms of their functionality (i.e., the action/use for which the system is designed to perform) and capability (i.e., the ability necessary to perform a function), can be placed are *roles* (i.e., what needs to be done), *agency* (i.e., who is doing what needs to be done), and *authority* (i.e., who initiates or authorises what needs to be done and by whom).

1.5.1 Human-Machine Roles

There are many roles that can be shared between the human operator and the machine. More recent research has included the roles undertaken by the human and machine within frameworks of the level of automation. Kaber and Endsley (2004) determined that there are four roles that can be shared between human and machine: monitoring, generating, selecting and implementing. Parasuraman, Sheridan and Wickens (2000) applied a more cognitive approach and determined that there are five roles: sensory processing, perception/working memory, decision making and response selection. Neisser (1976) formulated the concept of a ‘perceptual cycle’, where the interaction between human and environment shapes the human’s perceptions, decisions and actions. In this view, cognition is a continuous cycle of perception, decision and action where these processes occur in parallel and with different foci. Each of these processes provides both cognitive limitations and unique human strengths. Similar frameworks can be found in Perceptual Control Theory (Powers, 1973; Hendy et al., 2001) and models of Situation Awareness in dynamic decision making (Endsley, 1996).

Figure **2: Summary of Roles shared between Human and Machine.** This figure represents a synthesis of all of the approaches cited above:

- *Information Acquisition*. Consists of the roles: observing, perceiving, sensory processing, and monitoring (e.g., the machine obtains information from different sources and presents the information to the operator);

- *Information Analysis*. Consists of the roles: orienting, assessing, perception/working memory, and generating (e.g., the machine provides filtering, distribution or transformation of data, providing confidence estimates and integrity checks, and enabling operator requests, and the machine may also manage how this information is presented to the operator);

- *Decision Making*. Consists of the roles: deciding and selecting (e.g., the machine provides support to the operator’s decision making processes, either unsolicited or by operator request, by narrowing the decision alternatives or by suggesting a preferred decision based on available data); and,

- *Action*. Consists of the roles: acting, responding to selections, and implementing (e.g., the machine executes actions or controls tasks with some degree of autonomy).

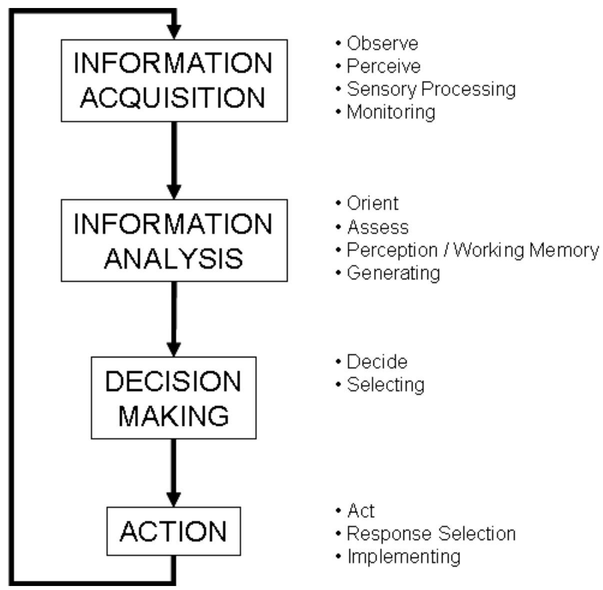


Figure 2: Summary of Roles shared between Human and Machine.

1.5.2 Human-Machine Agency

The function allocation between human and machine (assigning tasks to either human or machine), and the question of “who is doing what needs to be done?”, has generated much research interest since the conception of automation technologies. Early endeavours were largely based on approaches such as the approach proposed by Fitts (1951).

Fitts created a set of criteria where the human can exceed machine capability. These criteria included:

- The ability to detect small amounts of visual or acoustic energy;
- The ability to perceive patterns of light or sound;
- The ability to improvise and use flexible procedures;

- The ability to store very large amounts of information for long periods and to recall relevant facts at the appropriate time;
- The ability to reason inductively; and,
- The ability to exercise judgement.

Fitts further created a set of criteria where machines can surpass human capability. These criteria included:

- The ability to respond quickly to control signals and to apply great force smoothly and precisely;
- The ability to perform repetitive and routine tasks;
- The ability to store information briefly and then to erase it completely;
- The ability to reason deductively (including computational ability); and,
- The ability to handle highly complex operations (i.e., to perform many different functions simultaneously).

The sort of function allocation advocated by Fitts ignores the fundamental question: how do changes to the allocation of tasks affect operator performance? The cognitive abilities and deficiencies of an operator (such as attention, learning, boredom, fatigue, etc.) are of paramount importance to the safe operation of a system. While machines can out perform an operator in a monitoring task, humans excel in the ability to adapt when situations change. The issue is not that Fitt's list is incorrect; contemporary approaches are guided by more recent knowledge of the strengths and limitations of human performance from cognitive psychology. The issue is that this list was often (erroneously) taken to imply that these capabilities were static and separate.

1.5.3 Human-Machine Authority

Finally, the question of "who initiates or authorises what needs to be done, and by whom?", was once thought of as relatively binary (i.e., the authority rests with either the human or the machine). Perhaps the most commonly-cited taxonomy of the allocation of function between human and machine was produced by Sheridan and Verplank (1978) (see Table 1: Levels of automation.

The taxonomy describes levels of automation ranging from the human to the machine being in control. When the human is in control the operator makes virtually all the decisions and carries them out. When the machine is in control it decides whether a task must be completed, and only informs the human if the task is deemed appropriate. There is a clear dichotomy in this taxonomy; the human is in control of the automation from levels 1 through, 5 and the machine is in control of the automation from levels 6 through 10.

As level of automation increases from levels 1 through 3 (i.e., decision making tool), levels 4 through 6 (i.e., Operator Assistant), levels 7 through 8 (i.e., Operator Associate), and levels 9 through 10 (i.e., Autonomous Agent), the amount of responsibility for higher level functions, such as Decision Making and Action, also increases.

Table 1: Levels of automation (Sheridan and Verplanck, 1978).

Level	Description
1	The machine offers no assistance, human must do all the tasks.
2	The machine offers a complete set of action alternatives, and
3	narrows the selection down to few, or
4	suggests one, and
5	executes that suggestion if the human approves, or
6	allows the human a restricted time to veto before automation execution, or
7	executes automatically, then necessarily informs the human, or
8	informs him after the execution only if he asks, or
9	informs him after the execution if it, the computer, decides to.
10	The computer decides everything and acts autonomously, ignoring the human.

Sheridan's and Verplank's taxonomy was originally conceived for tele-operation activities and focuses little about the roles involved in Information Acquisition and Information Analysis. In response to this limitation, Endsley and Kaber (1999) modified this taxonomy to include the roles of monitoring (i.e., Information Acquisition), and generating (i.e., Information Analysis), as well as the roles of selecting (i.e., Decision Making), and implementing (i.e., Action) (see

Table **2**).

Table 2: Levels of automation (Endsley and Kaber, 1999).

	Roles			
Level of automation	Monitoring	Generating	Selecting	Implementing
(1) Manual control (MC)	Human	Human	Human	Human
(2) Action support (AS)	Human/Computer	Human	Human	Human/Computer
(3) Batch processing (BP)	Human/Computer	Human	Human	Computer
(4) Shared control (SHC)	Human/Computer	Human/Computer	Human	Human/Computer
(5) Decision support (DS)	Human/Computer	Human/Computer	Human	Computer
(6) Blended decision making (BDM)	Human/Computer	Human/Computer	Human/Computer	Computer
(7) Rigid system (RS)	Human/Computer	Computer	Human	Computer
(8) Automated decision making (ADM)	Human/Computer	Human/Computer	Computer	Computer
(9) Supervisory control (SC)	Human/Computer	Computer	Computer	Computer
(10) Full automation (FA)	Computer	Computer	Computer	Computer

Human-Machine authority can be viewed as a continuum between *adaptive* systems (i.e., machine-initiated adaptivity) on one end of the continuum, and *adaptable* systems (i.e., human-initiated adaptivity) on the other end, with varying degrees of human authority and involvement in the middle (Oppermann and Simm, 1994; see Figure 3).

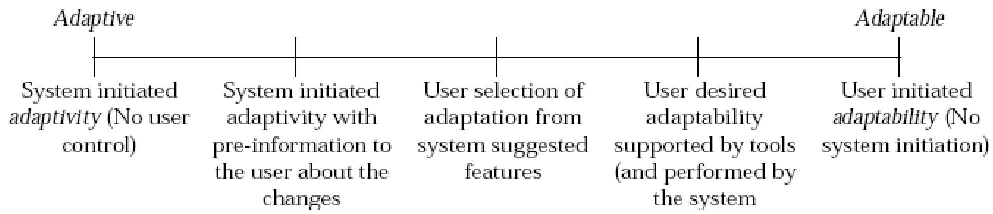


Figure 3: Spectrum of Adaptivity (Oppermann and Simm, 1994).

This classification of adaptive systems on basis of authority comprises five categories based on information the human is given about the systems status, and how much control the machine and human have over the initiation of the adaptation. Oppermann and Simm define these categories as:

- *Adaptive*. The machine has total control over adaptation;
- *System-initiated adaptivity*. The machine will notify the human of any changes prior to their execution. The operator still has no control over the choice, timing or implementation of adaptation;
- *Operator selected adaptation*. Using suggestions from the machine, the human selects the adaptation. The machine still performs the action;
- *Operator-initiated adaptability*: The human chooses and initiates the adaptation, without any suggestions from the machine, but the machine implements the change; and,
- *Adaptable*. The human is in complete control of adaptation.

Oppermann and Simm's spectrum of activity is a good example of the lack of integration between the HF and HCI fields of research. Sheridan and Verplanck were not acknowledged by Oppermann and Simm even though there are obvious conceptual similarities between their taxonomic classifications.

1.5.3.1 Human versus Machine Authority

There are two main modes of control over function allocation (Rieger and Greenstein, 1982). *Explicit* allocation refers to situations where the operator has allocation control over whether tasks are to be performed automatically by the machine or manually by the operator. *Implicit* allocation refers to machine allocation of tasks (Tattersall and Morgan, 1996). When comparing explicit and implicit modes of adaptive automation research indicates that although most operators prefer explicit control, implicit adaptive automation is superior in terms of overall system performance (Greenstein Arnaut, and Revesman, 1986; Lemoine Crevits, Debernard, and Millot, 1995). Although implicit adaptive automation affords lower levels of operator workload, a trade-off has to be made; there is an increased risk of operator out-of-the-loop problems (see Section 10.1.1).

Many approaches (Cook, Woods, McColligan, and Howie, 1990; Endsley, and Kiris, 1995; Lee and Moray, 1992) to adaptive automation assume that operator control over function allocation is preferable to the machine having control; or at the least consent should be mandatory. This assumption reflects the error-critical nature of the domains that are researched (e.g., aviation, war-fighting, process control). Harris, Goernert, Hancock and Arthur (1994) looked at the comparative effectiveness of machine-initiated automation and operator-initiated automation during anticipated and unanticipated increases in task load. When participants received written warnings that workload increases were likely to occur, performance during the operator and machine-initiated automation did not differ. When there was no warning before workload increase, resource management error was greater during periods of operator-initiated automation. The results suggest that machine-initiated automation is most beneficial when rapid workload increase occurs without warning, and that when operator initiation is necessary, responses to rapid task load increases improve when warnings are provided.

1.5.4 R-A-A Framework for Intelligent Adaptive Systems

It is noted that all intelligent adaptive systems cited in this review share the same three attributes: *role*, *agent*, and *authority*. The R-A-A (Roles-Agent-Authority) framework was then developed here to classify all the systems along these three discrete dimensions as illustrated in Figure 4. These three dimensions are:

1. *Role*. What are the tasks/activities that need to be done: information acquisition, information analysis, decision making, and action;

2. *Agent*. Who is performing the role: the human, machine or both; and,

3. *Authority*. Who authorises or initiates the Agent performing the Role: human, machine or both.

For an intelligent adaptive system, all tasks the system performs can be divided into four categories: information acquisition, information analysis, decision making, and action. The system needs to be designed to have relevant functions to conduct these tasks. An agent needs be assigned to play the role to perform these tasks. The decision of which agent (either a human or a machine or both) to initiate the tasks needs to be made by either a human or a machine or both.

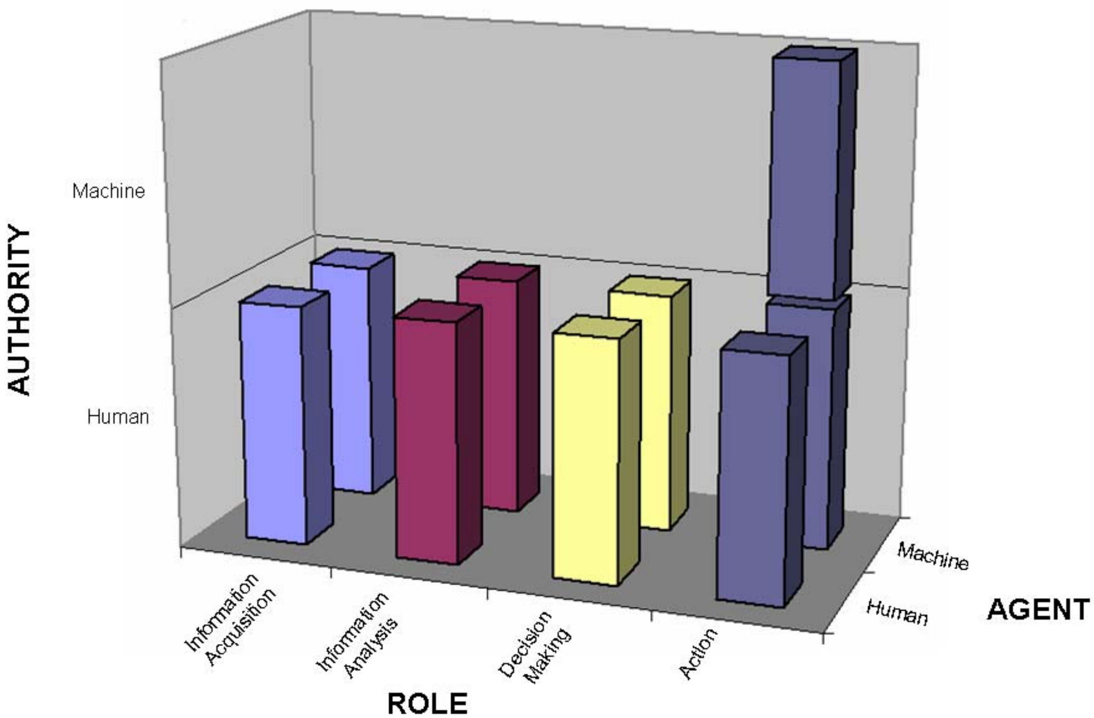


Figure 4: The Cognitive Cockpit Intelligent Adaptive System classified under the dimensions of Role, Agent and Authority.

The Cognitive Cockpit programme (Figure 4) is a typical example to illustrate how this framework will be used to classify all intelligent adaptive systems reviewed in this work. Allocation of function between the operator, or pilot, and the machine is very flexible in the Cognitive Cockpit: both pilot and/or the machine can take on the roles of information acquisition, information analysis, decision making and action. The machine is only able to perform these roles under the consent of the pilot; with the exception of some actions that might take place if the pilot is incapacitated (e.g., machine-initiated control of the aircraft in the event the pilot loses consciousness in a high *gravity* turn). It is important to note that the RAA framework represents a full-range of system tasks.

1.6 Literature Review Objectives

Functional architectures commonly exhibit the following attributes:

- The ability to predict operator expectations, intentions and actions based on detailed embedded knowledge of mission plans, goals, activities and alternatives and of the environment;
- A model of human decision making and control abilities, and of communication with other human and non-human agents;
- The ability to monitor operator performance and workload through behavioural and physiological indices; and,
- The ability to adapt system activities to the external situation and the changing abilities as well as the limitations of the operator. This adaptation could involve the fusion or filtering of information for displays, the management of workload, or the presentation of information tailored to the operator's cognitive style.

These architectures enable intelligent adaptive systems to provide flexible, 'intelligent' assistance to an operator, in the context of both the operator's needs and the external situation.

The objectives of the literature research were to:

1. Review theoretical frameworks, and compare them to design concepts developed in the DRDC UAV Interface Design project;
2. Review analytical approaches in order to capture the requirements of the OMI display as well as communication and control, and the functional decomposition of the domain envisaged for the IAI. In addition, identify means to capture more detailed knowledge from Subject Matter Experts (SMEs) for embedding in a Knowledge Based System (KBS). This process provides information about the states of the platform within a mission context and provides a basis for the adaptation of the interface to support the operator;
3. Review recent approaches to understanding and aiding human interaction in real-world systems from a multi-agent perspective;
4. Review techniques for the analysis of the psychological, physiological and behavioural states of the operator in order to provide information about the objective and subjective state of the operator within a mission context. As with knowledge of the external context, information about the internal (i.e., operator) context provides the basis for an intelligent adaptation of the interface to support the operator to achieve system goals;
5. Attempt to consolidate the HF and HCI approaches to IASs by developing consistent terminology that maps to both approaches by focusing on system functionality and capability; and,
6. Develop guidance for developers to assist in the successful design, development and implementation of IASs.

Each objective was achieved.

2 Method

This section outlines the methods used to review, and select the literature on IASs.

2.1 Approach

The approach to the literature review had three steps:

- *Literature search*. Following the development of appropriate search criteria approved by the Scientific Authority (SA) (e.g., keywords, authors, organizations), the CAE Professional Services (Canada) (CAE PS) team searched scientific, defence (e.g., Canada, United Kingdom, United States defence and NATO reports), government (e.g., DRDC Toronto reports and other documentation provided by the SA) and internet-based sources for literature pertaining to intelligent adaptive systems;
- *Reduce and collate literature.* In collaboration with the SA, the CAE PS team developed an Excel spreadsheet database to classify references by Level of Experimentation, Peer Review, Domain Relevance and Literature Review Area. The results of the literature search were collated and reduced according to appropriate selection criteria. Each article was appraised for: the degree of peer review (e.g., technical report, conference proceedings, journal article), degree of experimentation involved (e.g., conceptual study involving no experimentation, laboratory-based experimentation, field-based studies), and proximity to military domains. Recommendations or guidelines developed from sources involving experimental studies within the military domain that have been subject to critical peer review were given more prominence in the report than those that have been developed from more generic, conceptual sources, or that were subject to little or no peer review. All references were earmarked for inclusion into or exclusion from the final review, and classified according to area (i.e., conceptual frameworks, analytical techniques, design principles, and physiological/behaviour-based adaptation);
- *Development of reporting structure*. From the collated literature, a structure was developed for reporting findings in conjunction with the SA; and,

2.2 Structure

The objectives described in Section 7.1 were used to structure the literature review. The literature review was looked at the following:

1. *Conceptual Frameworks.* This is a review of theoretical frameworks, such as those adopted by the Cognitive Cockpit, Pilot's Associate programmes, and the DRDC UAV Interface Design project. The literature research reviewed, selected and described conceptual frameworks for designing IASs, including, but not limited to, those described above. In addition, the review also highlighted important similarities and differences, and advantages and disadvantages, between the theoretical approaches;

2. *Analytical Techniques*. This is a review of analytical techniques that capture the requirements and analyze the OMI display, communication and control as well as the functional decomposition of the domain imagined for the intelligent adaptive system. The review of analytical techniques provided a means of capturing more detailed knowledge from Subject Matter Experts for embedding in a Knowledge Based System. These processes provide information about the objective states of the platform within a mission context. They also provide a basis for the adaptation of the automation and/or interface to intelligently support the operator. The review also highlighted important advantages and disadvantages between the analytical approaches;

3. *Agent-based Design Principles*. This is a review of approaches to understanding and aiding human interaction in real-world systems from a multi-agent perspective. The literature research reviewed, selected and described issues relevant to the understanding and interaction between human and machine agents in the design of IASs (e.g., team work, organisation); and,

4. *Operator-state Monitoring Approaches.* This is a review of techniques for the analysis of the psychological, physiological and behavioural states of an operator in order to provide information about the objective and subjective state of an operator within a mission context. As with knowledge of the external context, information about the internal (i.e., operator) context provides the basis for an intelligent adaptation of the automation and/or interface to support the operator to achieve system goals. The literature research reviewed technologies for designing behaviour-based and physiological-based interface systems, and compared differences between behaviour-based and physiological-based techniques and also identified the benefits of combining the two techniques.

The literature review is summarized in Figure 4. The three sections of the literature review relate to a typical human-machine system development structure: conceive, analyze, design and implement. The content of each of the four sections is also outlined.

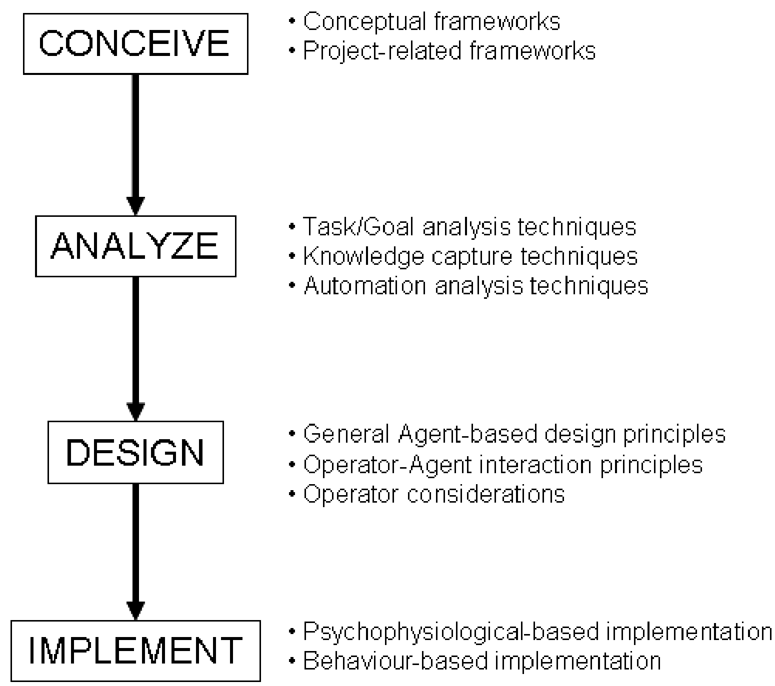


Figure 4: Overview of literature review structure.

2.3 Summary of Articles Reviewed

The following section outlines the number and type of articles reviewed. Table 3 describes the number of articles allocated to each of the four literature sections: conceptual frameworks; analytical techniques; agent-based design principles; and, closed-loop adaptation implementation.

Table 3: Number of references used in the literature review grouped by topic.

	Literature Review Topic Area			
	Conceptual Frameworks	Analytical Techniques	Agent-based Principles	Closed-loop Adaptation
Total References	68	32	113	24

Table 4 describes the number of articles classified in terms of the level of experimentation involved, the degree of peer review as well as the proximity and relevance to military domains. The level of experimentation had four categories: conceptual, single lab evaluation, single sim/field evaluation. ‘None’, ‘conference’ and ‘journal’ were three categories of peer review. Under domain relevance was ‘basic’, ‘business’, ‘industrial’ and ‘military’.

Table 4: Number of references grouped by level of experimentation, peer review and domain relevance.

	Level of Experimentation				Peer Review			Domain Relevance			
	Conceptual	Single Lab Evaluation	Single Sim/Field Evaluation	Multiple Evaluation	None	Conference	Journal	Basic	Business	Industrial	Military
Total References	63	27	39	29	47	88	24	36	14	20	90

The statistics show that:

1. A large number of articles have been written in all four topic areas;
2. The articles are mostly conceptual or single laboratory-based studies (57%);
3. The articles are mostly subject to little peer review (85%); and,
4. A significant proportion of the articles are from the military domain (28%).

2.4 Critique of Literature

The literature reviewed in this report was evaluated as followed:

- Each article is appraised in terms of its domain relevance (i.e., proximity to the military domain), and scientific impact (i.e., degree of peer-review and level of experimentation); and,
- A summary table following every section of the report has been developed to describe the advantages and disadvantages of the approaches, methodologies and frameworks.

2.5 Example of Reference Format

Each reference was formatted according to the format presented in Table 5 (also see accompanying legend). The intention was to impose a consistent and logical format to assist the reader in extracting the important information and guideline(s) quickly.

Table 5: Example of reference format.

① 

Reference: ②

Taylor, R.M. (2001). Technologies for supporting human cognitive control. In Proceedings of the RTO HFM Specialists' Meeting on Human Factors in the 21st Century, Paris, France, 11-13 June 2001.

Overview: ③ ④

ROLE	AGENT	AUTHORITY
ACQUIRE	💻 😐	😐
ANALYZE/ PRESENT	💻 😐	😐
DECIDE	💻 😐	😐
ACT	💻 😐	💻 😐

Details proof-of-concept demonstration of the Cognitive Cockpit research program that seeks to couple on-monitoring of pilot functional state assessment, environment and mission plan. Framework used to base KBS (roles) and adaptation (automation) was feed-forward (operator and system) and feed backward (system) control tasks. CommonKADS knowledge engineering methodology led to development of several knowledge-level models: organisational, task, agent, knowledge, communication and design models.

The Cognitive Cockpit is a multi-agent system:

Cognition Monitor (COGMON): monitors pilot functional state (level of arousal and workload). Based on cognitive model.

Situation Assessor (SASS): monitors environmental and aircraft state and recommends actions. Based on organization, task and knowledge models. Provides info about aircraft, within mission context and supports decision process.

Tasking Interface Manager (TIM): implements adaptation based on COGMON and SASS (e.g., maximum goodness of fit between aircraft status, pilot state and tactical assessments).

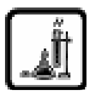
Pilot Authorizing and Control Tasks (PACT): operator initiative decision aiding for implementing automation. Based on roles/stages of information processing.

Dynamic adaptive interface: automatically assigns roles to system or operator according to operator agreed, context-sensitive adaptive rules.

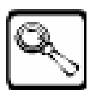
Conclusions for IASs: ⑤

1. Need to be based on User Centred Design (UCD).
2. CommonKADS methodology and PC PAC software toolkit for knowledge engineering useful for implementing KBS.
3. Timing is critical for effective contextual KBS advice.
4. Refer to requirements analysis within Cognitive Cockpit project for specific analyses used for development of each agent.

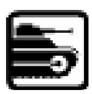
① *Ratings*. An iconic representation of the impact of the article. Impact is defined as:



Level of experimentation: Captures the *weight of argument* behind guidelines identified from the article. This is expressed in terms of the following colour-coding: red = conceptual, non-experimental study; yellow = single laboratory experiment or single simulator/field experiment; and, green = multiple experimental studies.



Degree of peer review: Captures the *confidence* in which the weight ascribed to an article using the criteria above. This is expressed in terms of the following colour-coding: red = no peer-review; yellow = cursary peer-review typical of most conference proceedings; and, green = intense, critical peer-review typical of most journals.



Proximity to military domain: Captures the *proximity* of an article to the military domain. This is expressed in terms of the following colour-coding: red = no specific target domain; yellow = industrial or business target domains; and, green = military target domain.

② *Reference*. Full reference of article.

③ *Overview*. Summary of the main conceptual or empirical points of the reference.

④ *System Classification (if applicable)*. Tabular representation of the type of system discussed in the article in terms of Role (i.e., what needs to be done), Agent (i.e., who is doing what needs to be done) and Authority (i.e., who authorises and/or initiates what needs to be done and by whom). This classification is described in more detail in Section 6.4. The human operator is depicted by the ☺ icon, and the machine is depicted by the  icon.

⑤ *Conclusions for IASs*. A list of design guidelines or recommendations taken from the article that is relevant to the development of an IAS.

3 Conceptual Frameworks for Intelligent Adaptive Systems

3.1 Introduction

The origins of intelligent adaptive systems are in the early stages of development of the crew adaptive cockpit (Reising, 1979). The development of intelligent aiding from that point forward is tracked in the series of USAF/RAF conferences on teamwork with the Electronic Crewmember (Taylor and Reising, 1999). Intelligent Aiding systems previously attempted, and those currently under construction operate at the level of Assistant (e.g., Germany CASSY/CAMMA, France Co-pilote Electronique) and Associate (e.g., USAF Pilots' Associate and US Army Rotorcraft Pilots' Associate Programmes). However, technological advances in both Artificial Intelligence and physiological monitoring of human performance have the potential for allowing higher levels of Intelligent Aiding to be realised, such as providing an operator with a more useable and non-intrusive interface by managing the presentation of information in a manner appropriate to the mission content (i.e., intelligent adaptive interfaces).

Conceptual frameworks are required to enable such systems to provide 'intelligent' assistance to an operator in the context of the operator's needs and the external situation. The requirement to provide support in the appropriate internal and external 'context' is then implemented through a functional architecture reflecting the attributes of the conceptual framework (Taylor and Reising, 1999):

- A model of human decision making and control abilities;
- The ability to monitor operator performance and workload through behavioural and physiological indices; and,
- The ability to predict operator expectations and intentions with reference to embedded knowledge of mission plans and goals.

Sections 8.2 through 8.4 review a number of conceptual frameworks for designing intelligent adaptive systems including, but not limited to those frameworks identified above. The review also highlights important similarities and differences, and advantages and disadvantages, between the conceptual approaches. The sections are structured according to Intelligent Adaptive Interfaces, Intelligent Adaptive Automation, and Intelligent Adaptive Hybrid systems. As discussed in Section 6.1, IAHs reflect the utilisation of both adaptable automation and an adaptable interface within the same system (Figure 1).

3.2 Intelligent Adaptive Interface (IAI) Frameworks

This section reviews the following IAI frameworks:

- Situation Awareness Assistant (SAWA);
- Stock Trader;
- Personal Web Searcher;
- Decision-Theoretic InterAction Manager for Discourse (DIAManD);
- Work-centered Decision Support (WCSS);
- Adaptive Icon Toolbar; and,
- ConCall System.

3.2.1 Situation Awareness Assistant (United States)

Reference:

Matheus, C.J., Kokar, M.M., Baclawski, K., Letkowski, J.J., Call, C., Hinman, M., Salerno, J., and Boulware, D. (2005). Lessons learned from developing SAWA: A Situation Awareness Assistant. Technical report Air Force Research Laboratory, Rome, NY.

Overview:

This paper details the Situation Awareness Assistant (SAWA) project and various lessons learned during its development; including the pros and cons of leveraging semantic web technologies, the handling of time-varying attributes and the processing of uncertainty.

ROLE	AGENT	AUTHORITY
ACQUIRE	💻 😐	💻 😐
ANALYZE/ PRESENT	💻	💻
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SAWA: The authors view situation awareness as a fusion problem. Therefore, the SAWA project developed specific domain knowledge database offline. This database can then be applied in real-time to fuse and analyse data.

SAWA Process:

1. Domain knowledge is captured in SAWA using formal ontologies. Formal ontologies can provide a flexible query and monitoring language that can be used to request information to increase situation awareness. These queries can include information about the current situation, predicted situations and request notifications of current or potential future emergency conditions.
2. Semantic Web Ontology Language (OWL), is used to define ontologies which provide a formal set of semantics. Data and knowledge representation use these semantics as a basis within the SA system.
3. Semantic Web Rule Language (SWRL) is used on top of OWL to define portions of the domain knowledge using rules.

4. Situation Awareness Core Ontology was used to develop specific domain knowledge ontologies and rule sets.

The SAWA High-level Architecture has two aspects: a set of offline tools for Knowledge Management and a Runtime System of components for applying domain knowledge to the monitoring of evolving situations.

The operator interacts with the system through a Graphical User Interface (GUI) by executing queries and monitoring the current state of events.

Automation: Information is acquired, analyzed and synthesized to assess current situations and generate possible future situations to support decision making.

Conclusions for IASs:

1. The authors advocate that Semantic Web technologies can be used for representing and reasoning about knowledge pertinent to a situation's domain but that they are difficult to implement.

2. The authors also claim that the behaviour of dynamic objects within its domain ontology should be modelled in order to provide up-to-date situation awareness of all objects/events at all times.

3. Representation of certainty (or uncertainty) should be presented to ensure that the operator is aware of the system's reasoning processes. The authors resorted to using Bayesian reasoning within their inference engine to manage uncertainty.

3.2.2 Stock Trader

Reference:

Yoo, J., Gervasio, M., & Langley, P. (2003). An adaptive stock tracker for personalized trading advice. Proceedings of the International Conference on Intelligent User Interfaces, pp. 197

Overview:

The Stock Trader system investigated operator performance. The system addresses information overload by tailoring recommendations based on an individual operator's investment styles. The system utilizes this profile to rank stocks, and it revises the profile based on traces of operator behavior. The system automates information acquisition; it encompasses sensing, and registers input data.

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The system architecture is composed of the following elements:

1. *The data processing unit* converts raw input (i.e., current stock readings and historical trading information) into reports that contain buy and sell recommendations for the operator. It relies on the recommendation module to make appropriate suggestions for each stock based on individual operator profiles.
2. *The user modeler* which constructs these profiles is based on operator responses to previous recommendations (implicit).

3. *The information manager* records traces of an operator's interactions with the system and also maintains awareness of operator portfolios.
4. *The communication unit* manages the information into and out of the server.
5. A client contains a communication unit and a graphical user interface component.

Results from a study conducted with novice stock traders indicated that as the system learned through interaction with the operator's past behaviour, the traders' acceptance of recommendations increased. Furthermore, as the traders' began to better understand how the system operates, they also began to accept more recommendations.

<u>Conclusions for IASs:</u>

1. An implicit user model is an effective and non-obstructive means of constructing a user model.

3.2.3 Personal Web Searcher

<u>Reference</u>:

Armentano, M., Godoya,D. and Amandi, A. (2006). Personal assistants: Direct manipulation vs. mixed initiative interfaces. International Journal of Human-Computer Studies 64 (2006) 27–35

<u>Overview:</u>

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This paper explores new mixed-initiative metaphors to enhance an operator's ability to directly manipulate interfaces. Mixed-initiative interaction is referred to as a flexible interaction strategy in which agents are used to manage information overload. A study evaluating how the interaction metaphor can affect the operator perception of agent capabilities is reported.

The mixed-interface is the "PersonalSearcher", an intelligent agent that builds an operator profile implicitly by observing operator behaviour while operators are performed regular activities on the Web. An agent is able to deduce the topics an operator are interested in to create an operator profile by using a content-based analysis of the information extracted by observation.

The study compared two interfaces: 1) an operator interacts with the interface directly and has no control over displayed suggestions (automation) and 2) an operator interacts with an animated "agent" instead of the interface and has control over suggestions (mixed-initiative).

Results indicate that the mixed-initiative interface increased situational awareness (i.e., operators noticed improvements in the agent suggestions over time), but that participants were more critical of suggestions.

Conclusions for IASs:

1. Mixed-initiative interfaces (e.g., direct interaction with an agent) can increase situational awareness and develop a better mental model of the system.

2. Designers must be careful when designing mixed-initiative interfaces to ensure a proper mental model of the system is achieved.

3.2.4 Decision-Theoretic InterAction Manager for Discourse

Reference:

Wolfman, S.A., Lau Pedro Domingos, T and Weld, D.S. (2001). Mixed Initiative Interfaces for Learning Tasks: SMARTedit Talks Back. In proceedings of IUI'01, January 14-17, 2001, Santa Fe, New Mexico, USA.

Overview:

ROLE	AGENT	AUTHORITY
ACQUIRE	💻	💻 😐
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An interface for machine learning is proposed. The paper describes a variety of interaction modes that enhance the learning process and presents a decision-theoretic framework, called DIAManD, for choosing the best interaction.

The authors propose that machine learning systems should closely resemble human teacher-student relationships and follow the example of the proactive yet considerate student. For instance, the system should ask questions, propose examples and solutions, and relate its level of knowledge when appropriate to make the interaction more effective.

DIAManD is a system for selecting among various interaction modes using a multi-attribute utility function. The interaction modes provide a variety of methods for an operator to interact with the system. The system selects from a set of interaction modes the mode it judges most appropriate based on attribute vectors. The best of these modes is presented to the operator and controls the next stage of discourse, updating the state of the learner. The modes are then rescored based on the new state of the learner.

The paper outlines and describes the interaction modes.

Conclusions for IASs:

1. The authors advocate a mixed-initiative interface in which the machine learner and human operator equally share responsibility for guiding the learning process.

2. A learning system should have several modes of interaction with the operator to acquire the concepts more quickly (e.g., through judicious choice of the example to classify, as in active learning) and should allow the operator to have more control over the learning process. See paper for details on interaction modes.

3. A mixed-initiative framework (e.g., DIAManD), where the learner and human operator are each participants in a dialogue, could improve the learner's hypothesis with minimal effort on the

part of the operator.

4. The operator of a system should be able to override the system's choice of interaction mode and choose a mode that he/she prefers.
5. To facilitate rapid learning, the interface should provide some mechanism for feedback to the learning system on particularly poor interaction mode choices (the feedback model is further described in the article).
6. An attribute set must reflect the balance between operator effort and the value to the task and system.
7. The authors recommend five appropriate but general attributes, each of which should be viable for most learning system and interaction library combinations. The attributes (operator input, level of continuity, and probability of correction) focus on operator effort and represent the physical and mental effort required from an operator. The attributes (task progress and value to the system) focus on the achievement of an operator's objective. These measures reflect an operator's typical objective of a machine learning system, which is: complete the task by refining the hypothesis of the learning system until it correctly describes the data.

3.2.5 Work-Centered Decision Support

Reference:

Young, M.J. and Eggleston, R.G. (2002). Work-Centered Decision Support. In Proceedings of RTO Human Factors and Medicine Panel (HFM) Symposium held in Warsaw, Poland, 7-9 October 2002

Overview:

The Work-Centered Decision Support system is a stand-alone interface client that manages information. The system employs intelligent agents that dynamically plug into an information grid to find, fuse, format, and present information to an operator in a manner relevant to the current context. The system is based on a task model and work domain ontology model. Cognitive task analysis techniques were used to acquire the information to build the task/model.

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The WCSS system is composed of three layers:

Acquisition Agent: This agent contains knowledge on how to find and retrieve data. The agent's function is to automatically monitor and access data sources for an operator and notify other agents when new data has been retrieved or received (information acquisition).

Analysis Agents: These agents contain the knowledge required to transform data into information that will support decision making. Their function is to provide data reasoning and fuse data to create patterns of information. These agents use the data collected by the acquisition agents to continually appraise the situation, proactively identifying possible problems, and dynamically generating a prioritized list of potential operator actions (information analysis).

Presentation Agent: This is a communications and dialogue module that controls the information presented on the screen, the response to operator requests, and the provision of alerts to the operator to identify potential problems and opportunities. This agent aggregates or disaggregates information based upon who the operator is, and what the operator's current requirements are. The interfacing agent is an ecological interface.

An example of this framework was applied to a Work-Centered System for Global Weather Management to support weather forecasting in a military airlift service (Refer to the paper for further details).

The authors claim that the two most important research areas for the future development of the WCSS are the role of agents in the interface, as well as improving the creation of analysis agents by developing extensions to cognitive task analysis techniques.

Conclusions for IASs:

1. A Work Domain ontology was useful to provide an organizing framework.
2. The reference to task domain elements in on-screen information displays should be made more explicit.
3. Fusion of data from multiple databases can be useful to identify and complete work tasks.
4. The authors believe that the introduction of *social agents* could potentially reintroduce unnecessary mental shifts in work, as the operator shifts from focusing on the task to "socializing" with the agent. The authors indicate that Milewski and Lewis (1997) claim that the use of agents as the interface (as opposed to having "behind the scenes" agents) usually involves a delegation model, where the operator delegates activities to the agents. The authors claim that delegating activities to agents (or other humans) requires many processes; the delegator must consider the competency of the agent, and then communicate outcomes and possible strategies, and monitor the progress in work. These activities require knowledge types different from other than domain task knowledge. The authors suspect this would introduce unnecessary shifts in focus, away from the task, as the operator applies "social knowledge" to commission the agent.
5. Task elicitation techniques could be used to identify models of decision making and cues used by skilled (or expert) decision-makers. The analysis agents could then be designed to identify patterns, and have the presentation agents present a rank ordered set of potential problem situations to the operator. In the current implementation of the WCSS, operators must manually search for cues, which they then integrate mentally. Automating this process has the potential to greatly improve decision-making quality and reduce human errors.
6. More research is required to determine which techniques are best suited for knowledge elicitation of schemas, and then to determine how to best map this knowledge into analysis agents to maximize work support.
7. The ecological interface provides an adequate means of supporting an operator's work tasks by providing contextual situational awareness; the ecological interface presents an action by making readily apparent what action is required and the constraints of that action (in WCC, the action is done by the operator).

Reference:

Eggleston, R.G., Roth, E.M., Scott, R.A. (2003). A Framework for Work-Centered Product

Evaluation. In proceedings of the 47th Human Factors and Ergonomics Society Conference, Denver.

Overview:

A comprehensive work-centred evaluation framework that assesses new technology for their value in supporting human performance is described. A key feature of the framework is that it encompasses: usability, usefulness and impact. This concept is illustrated through a work-centred support system prototype. The framework is detailed in Young, M.J. and Eggleston, R.G. (2002).

In the WCSS prototype, software agents are designed as small, independent chunks of software that address tasks as separately controlled and modifiable modules. This enables software components to be organized according to functional elements of work in a particular domain.

A detailed domain analysis was performed to map domain work requirements and systematically allocate tasks to human and software agents.

Structuring agents in functional terms provides a concrete vocabulary of concepts and metaphors that can be shared among software engineers, cognitive engineers, and operators.

Two types of interfacing agents are used in the prototype. The “visibility” of the agents is based on the task:

a. Agents organized around domain work. These include forecasting agents, region analysis and mission analysis agents, which are agents that operators “delegate” work to; they have no personality.
b. Agents that operators can access if needed. These include data acquisition agents.

Conclusions for IASs:

1. *Cognitive work analysis (CWA)* is an effective means of establishing system requirements. The authors advocate that sources of cognitive and collaborative demands should be analyzed in the applied domain and involve close interaction among the cognitive engineers, software developers and domain practitioners.
2. *Automated agents* should act as ‘team players’.
3. *Visibility of agents:* Automated agents need to be observable (or transparent/visible) so that operators are able to determine the current state of the automated agents, and understand what the agents will do next relative to the state of the task. The amount of “visibility” required is questionable (i.e., the issue of trust and mistrust can occur or fully visible such as the Microsoft “PaperClip” which takes advantage of assistant and subordinate metaphors)
4. Humans should have control and be able to re-direct the software agents as task requirements change.
5. A system needs to support multiple facets of individual cognitive and collaborative work. This involves consideration of problem-solving/decision-making aspects of work, activities involved in creating work products, processes involved in collaborative work, and the cognitive effort involved in tracking and managing multiple intertwined work activities.
6. Object-oriented design techniques are useful in facilitating collaboration between operators, cognitive engineers, and software engineers (although as system complexity increases, the operator can lose sight of the big picture).
7. Agent-based architectures provide potential for operator-accessible descriptions of domain

objects, workflow, and large-scale interactions between domain objects.

Reference:

Eggleston, R.G. (1992). Cognitive interface considerations for intelligent cockpits. Proceedings of the AGARD conference on Combat automation for airborne weapon systems: Mlockan/machine interface trends and technologies, Edinburgh, UK, 19-22 October 1992.

Overview:

This paper presents the concept of an intelligent cockpit as an example of a knowledge-based aiding system. Cognitive design requirements for aiding systems are presented along with illustrative examples.

Compared to conventional cockpits, the authors claim that an intelligent cockpit is much more flexible and adaptive in handling events. Intelligent cockpits, as opposed to conventional ones, have the ability to consider a wide range of data and issues that allow it to exhibit adaptive behavior.

Cognitive design requirements include all system factors that are essential for the system to behave at a symbolic and abstract level of understanding. The major challenge is how to adequately account for and predict the form of adaptive behavior that an operator will exhibit in a given task.

Conclusions for IASs:

1. Knowledge of human capabilities and limitations are important factors for the design of an intelligent interface; these factors include but are not limited to, attention, working memory, and an analysis bias (reasoning and decision making).
2. The cognitive architecture for an intelligent system should be designed so that an appropriate method of implementation of automation can be chosen that is based upon the situation.

3.2.6 Adaptive Icon Toolbar

Reference:

Debevc, M., Meyer, B., Donlagic, D., & Svecko, R., (1996). Design and evaluation of an adaptive icon toolbar. User Modeling and User-Adapted Interaction, 6(1), pp. 1-21.

Overview:

An adaptive icon toolbar in MS Word was evaluated. The time and errors taken to adapt the toolbar were examined during two tasks (formatting text and tables). The operator is always in control of adapting the toolbar but the system offers suggestions. Refer to the paper for further description regarding the decision-making algorithm implemented in the toolbar.

Adaptive toolbar. This is an operator-controlled self-adaptation system that adapts the OMI by observing operator actions, making proposals to adapt the icon bar to best reflect those actions, and, if the operator agrees, automating the process of customizing the toolbar.

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ANALYZE/ PRESENT	💻	😐
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Maintaining system awareness. Any change or proposal for change in the OMI is made visible to the operator by playing a tone and by changing the background colour of the toolbar. The toolbar colour reverts back to normal once the operator accepts or rejects the change. This alert eeps the operator in the loop while not disrupting work.

User model: The user model is based on operator interaction with the system (i.e., frequency of use of commands, options, and macros not already directly available in the interface). The paper provides more details on decision algorithms for adaptation.

Adaptation uncertainty. Uncertainty about the adaptation is displayed to the operator to identify when and how to adapt the interface (e.g., via size of the icon - unused icons grow smaller). The adaptation is based upon operator’s previous actions.

Conclusions for IASs:

1. *Adaptation can increase learning of system functionality and enhance performance. Study* results from the study showed that the adaptation of the toolbar allowed for more efficient customization as operators spent significantly less time adapting the toolbar. Adaptation also introduced novice operators to toolbar functionality and therefore increased learning.
2. The authors suggest several possible goals and benefits of adaptive interfaces including: adaptive interfaces should be easy, efficient, and effective, and should encourage faster and simplified use. Adaptive interfaces should increase the ease of working within complex systems and should present what the operator wants to see.
3. The authors recommend that an operator interface should consider operator increasing experience with the system in order to provide skill-specific automation.
4. Adaptation of the operator interface can increase efficiency of customization and learning of interface features.

3.2.7 Concall System

Reference:

Averman, C. (1999). Using "Human-in-the-loop" in an adaptive system: An evaluation study of the ConCall system. Unpublished master's thesis, Göteborg University, Goteborg, Sweden. Retrieved January 3, 2005 from http://www.handels.gu.se/epc/archive/00001335

Overview:

This paper discusses the evaluation of the Concall system which is used to reduce information overload by sorting and filtering call for papers and participation for conferences. It is considered a mixed interface; operators provide an explicit user model and the interface then produces recommendations based on the user model. Results indicate that the system provided too many recommendations and therefore, operators stopped using the system out of frustration. Operators also wanted an "UNDO" function and wanted to be less disturbed. Since the system lacked a proper mental model, operators' were found to request a function that would undo a previous adaptive change that the system has determined would be the right choice for the operator.

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Conclusions for IASs:

1. An explicitly elicited user model may not be the appropriate means to acquire a user model.
2. The operator must be fully understood in order to develop a user model that will provide efficient and usable adaptivity.

Section Summary

The frameworks reviewed emphasize the importance of user models and agent use with IAIs. These frameworks have been applied to address the issues of automation and human control of interfaces. The most important ability of an IAI is to understand the user and to communicate with him/her. A system needs to have the ability to intelligently appraise a situation and to adapt to the changing needs of the user and the situation. A multi-agent architecture is needed to integrate all the agents working collaboratively in a system to interact with the user. To achieve these goals, a unified framework is needed and the associated analytical methodologies should be categorized to address different task domains.

3.3 Intelligent Adaptive Automation Frameworks

This section reviews the following IAA frameworks:

- Crew Assistant Military Aircraft (CAMA);
- Co-Pilote Electronique;

- Delegated Systems (Playbook);
- Intelligent Classroom; and,
- Lookout.

3.3.1 Crew Assistant Military Aircraft (Germany)

The Crew Assistant Military Aircraft is a knowledge-based system that was developed by the University of the German Armed Forces (Munich), DASA, and DLR, for improving pilots' situation awareness in air transport. CAMA assists the crew in planning and decision making tasks through all flight phases.

CAMA consists of an "electronic crew member" which gathers information from the crew through monitoring control actions and through image processing of an inside cockpit camera. The internal and external data sources are connected to the system by appropriate sensors or communication media. The Central Situation Representation is a dynamic object-oriented representation of relevant data. This representation contains all situation related (dynamic) and domain related (static) knowledge. The Crew Interface is the audio-visual communication layer between CAMA and the crew. The interface selects and co-ordinates information to be shown on a 2D map display or to be issued via a speech synthesiser. The latter provides system control through speech recognition. The Planning Layer generates a complete flight mission plan. In the Situation Interpretation Layer this flight plan is used as a reference for the crew model. Here, the expected crew actions are elaborated and aspects of the external situation, such as tactical elements and terrain, are evaluated. The modules in the Situation Assessment layer are intended to detect conflicts in the expected succession of the flight and to recognise the crew's intent and error. In the case of a pilot error, a warning or hint is given to the crew to correct the error. In order to cope with the temporary discrepancy of crew intent, CAMA attempts to extract the intention, modify the flight plan accordingly, and elaborate the consistent expected behaviour again. The structure of CAMA mirrors the general design philosophy not to solely allocate functions to the machine side or the crew, but to both in parallel.

In order to incorporate tactical elements into CAMA's planning and decision making, the Tactical Situation Interpreter (TSI) and Low-Altitude Flight Planner (LAP) are integrated in the Situation Interpretation Layer:

- *Tactical Situation Interpreter*. The TSI is a knowledge-based module in the context of the CAMA Situation Interpretation Layer. The TSI contributes two main functional aspects: the computation of the Threat Map based upon a list of tactical elements such as surface-to-air missiles (SAMs) and other aircraft, decision aiding functions such as distance to threat calculations in order to transform sensor data into an intuitive format with respect to the human information processing capabilities of the crew. The calculations are based upon tactical elements which are either static and known, or provided by external communication modules which are fed into the Central Situation Representation; and,
- *Low Altitude Planner*. The LAP calculates a low altitude trajectory through the operation area based upon digital terrain data, the TSI's threat map, and on the basis of given plan parameters, such as waypoints. The process of low-level flight plan generation consists of two principle steps: the evaluation of the tactical situation,

which results in the calculation of the Threat Map, and the low-level flight trajectory optimisation. The trajectory optimisation considers the terrain elevation structure, the local threat value from the Threat Map, and constraints resulting from the general mission plan. The result is an optimal trajectory, minimising a cost function of weighted terrain elevation data and local threat values integrated over the complete flight path. The data are visualised in a 2D map display.

<u>Reference:</u>

Schulte, A. and Klöckner, W. (1998). Crew Assistant for tactical flight missions in simulator and flight trials. NATO systems concepts and integration panel symposium: The application of information technology (computer science) in mission systems. Monterey, California, USA. 20-22 April 1998.

<u>Overview:</u>

ROLE	AGENT	AUTHORITY
ACQUIRE	🖳	🖳 😐
ANALYZE/ PRESENT	🖳	🖳 😐
DECIDE	🖳	🖳 😐
ACT	🖳 😐	😐

The Crew Assistant Military Aircraft project, a result of CASSY project efforts, is described. This is a tactical mission management system that assists in situation assessment and fight planning.

The CAMA system was experimentally evaluated through a series of simulator flights with operational personnel (e.g., flight and simulator trials). Results showed high operator acceptance and a well-developed mental model of the system following training and repeated interactions with the system. Situation awareness concerning the tactical situation elements remained unchanged.

<u>Conclusions for IASs:</u>

1. Comprehensive knowledge bases are necessary for the implementation of knowledge-based systems.
2. *Task-based approach*. Functions derived from tasks relating to tactical low-level flight missions proved to be a successful in providing situation assessment and mission planning.

<u>Reference:</u>

Brugger, E. and Hertweck, H. (1995). CAMA: Some aspects of a military crew assistant system. Proceedings of the 3rd international workshop on human-computer teamwork (Human-Electronic Crew: Can we trust the team?). Cambridge, UK, 27-30 September 1994.

<u>Overview:</u>

The CAMA system is designed to assist the crew in enhancing of the situation awareness in all mission phases, from flight planning to the debriefing after landing. CAMA provides several types of operational support (e.g., preparation and execution of tactical navigation). Basic services are also available (e.g., check list routine work, fuel/load management, etc.)

The CAMA program consists of 16 separate modules for data acquisition and data control. These modules are grouped according to tracking goals/tasks (plan generator and recognition monitor); operator state (physio-behavioural monitor), world state (terrain, aircraft state and parameters and environment monitors), adaptation (pilot intent and error recognition, terrain interpreter), and interaction modules (interface).

Conclusions for IASs:

1. It is recommended that functional overlapping should be avoided between modules and pre-existent aircraft monitoring systems.

3.3.2 Co-Pilote Electronique (France)

Reference:

Joubert, T., Sallé, S.E., Champigneux, G., Grau, J.Y., Sassus, P., and Le Doeuff, H. (1995). The Copilote Electronique project: First lessons as explanatory development starts. Proceedings of the 3rd international workshop on human-computer teamwork (Human-Electronic Crew: Can we trust the team?). Cambridge, UK, 27-30 September 1994.

Overview:

The Co-Pilote Electronique program, which was initialized in 1986, focused on artificial intelligence support for problem recognition and situation assessment. This paper describes the first lessons learnt as a new phase of the French project "Copilot Electronique" (CE) that began in 1994. It details the development of the system and compares the advantages and drawbacks of existing methodologies.

ROLE	AGENT	AUTHORITY
ACQUIRE	💻 😐	💻 😐
ANALYZE/ PRESENT	💻	💻 😐
DECIDE	💻	💻 😐
ACT	💻 😐	😐

According to Taylor (1998), the French Co-Pilote Electronique programme aimed to provide cockpit assistance to the military fast-jet combat pilot. The CE approach was to provide assistance with situation assessment and planning (with multi-agent technology), but not plan execution (according to roles/stages model, this system provided automation of information acquisition, analysis and presentation and solution generation but no action). Intent recognition and intent planning are performed to minimize operator workload. The type of recommendations given by the system was modulated by the current situation and pilot mental load. The pilot interacted with the system through a “supervisor expert function”.

Three main risks were identified at the end of the phase:

1. It was not clear if it was possible to capture enough expertise to create real assistance for pilot reasoning.
2. There was doubt as to whether knowledge-based system technology was mature enough for the development of a real system.
3. It was still not clear if the French Aerospace community would be able to integrate such a new concept in current avionics systems design.

Conclusions for IASs:

1. The authors found that by the end of the first phase, conventional knowledge engineering techniques using questionnaires and interviews were not sufficient to provide implementable and secured knowledge for Pilot aids.
2. Common plans and goals exchange language between all specific assistance modules must be carefully defined (a technical issue).
3. The intent planning paradigm proved to be a useful unifying technical principle to facilitate architecture design.

3.3.3 Delegated Systems: Playbook (United States)

Reference:

Miller, C., Funk, H., Wu, P., Goldman, R., Meisner, J., Chapman, M. (2005). The Playbook Approach to Adaptive Automation, In Proceedings of the Human Factors and Ergonomics Society's 49th Annual Meeting, Orlando, FL

Overview:

ROLE	AGENT	AUTHORITY
ACQUIRE	💻 😐	😐
ANALYZE/ PRESENT	💻 😐	😐
DECIDE	💻 😐	😐
ACT	💻 😐	😐

Playbook is a human-system communication tool that allows delegated control of automation. The tool is based on a shared model of the tasks in a domain. This shared task model provides a means of human-automation communication about plans, goals, methods and resource usage, a process similar to referencing plays in a sports team's playbook. The Playbook enables operators to interact with subordinate systems with human subordinates, thus allowing for adaptive automation. This approach and its application is described through an ongoing project called Playbook-enhanced Variable Autonomy Control System™ (P-VACS).

Playbook is a specific method of implementing a delegation interaction which can be divided into two components: (1)a hierarchical task model that is compatible with levels of automation (cf. Sheridan, 1987); and (2) a planning mechanism for evaluating existing resources, plan validity, and instantiating the task models.

A shared task model is comprised of a set of *play templates* are generated by identifying a set of common tasks, grouping those tasks into plays, and enabling elements such as time and location to become task parameters.

How Playbook works. When a previously defined play is executed, the operator can select a play template and apply the parameter values as appropriate to his/her needs. Both the operator and the automation have a similar model of the sequence of tasks to execute (the shared task model).

The overall Playbook architecture consists of three components: a library of task models; a constraint-based planning engine; and an OMI.

Conclusions for IASs:

1. Findings provide support for allowing the tasking of multiple agents while keeping the supervisor in the decision-making loop, without increasing supervisor mental workload. It also suggests that the human supervisor can adapt successfully to unpredictable changes in the environment.
2. Playbook provides a complete architecture for the integration of human input, intelligent *a priori* planning, reactive planning and event handling, and ongoing vehicle control loops.
3. The authors recognize that new methodologies are still needed to build more extensive task models. For instance, Playbook task knowledge should arise from results of Cognitive Work Analysis of a task domain and then the Playbook architecture (including UI and planning components) can be used to produce useful task timeline inputs for a constructive simulation.

Reference:

Miller, C. and Goldman, R. (1999). Tasking interfaces: Associates that know who's the boss. In J. Reising, R. M. Taylor and R. Onken (Eds.). The human electronic crew: The right stuff? Proceedings of the 4th joint GAF/RAF/USAF workshop on human-computer teamwork, Kreuth, Germany (Technical report AFRL-HE-WP-TR-1999-0235 pp.97-102). Wright Patterson AFB, OH: Air Force Research Laboratory.

Overview:

This paper describes the techniques, adapted from the “associate” (PA) research, used for the construction of tasking interfaces. They present initial work on a solution, which allows human operators to interact with advanced automation at various levels. According to this model, tasked systems should always be sub-ordinate, but must know enough about the tasks in the domain. The authors claim that instructing these “tasking interfaces” is vastly easier than instructing traditional automated systems. Concepts are described and discussed in the context of a tasking interface for UAVs.

Playbook OMI

This is an interface that allows the operator to inspect and interact with the system (through a task model) by “calling plays” and activating tasks at various levels and sub-levels. Through this interface, the operator will graphically instruct a full or partial plan for the mission by specifying the tasks to be performed, or goals to be accomplished by the system (Figure 6).

Playbook Framework:

The framework is composed of four primary components:

1. **Playbook OMI**
2. **Mission Analysis**. A projective planning system which is capable of understanding instructions from the operator through the OMI.
3. **Event Handling.** All accepted plans are passed from the mission analysis module to “even

handling" where plans can be adjusted in real-time.

4. **Control algorithms**. Executes the instructions.

This framework is based upon and interacts with a Shared Task Model Infrastructure, which can facilitate human-system coordination.

Conclusions for IASs:

1. The authors stress that a usability evaluation of the tasking interface GUI (and all system interfaces) is required.
2. The authors warn that tasking interfaces should not rely on a predefined set of task models, but dynamic ones. The operator should be able to create novel tasks and to store components of models which are useful.
3. The authors acknowledge that their task network representation is weak in its coding of goals, which are seen as a critical component of any tasking interface.
4. Operators need sufficient training for interacting with the tasking interface.
5. A delegated interface may increase operator acceptance; that is, by enabling a system to behave more like an intelligent subordinate, operators may be more tolerant of their weaknesses and more acceptable of their capabilities in a controlled setting.

Reference:

Miller, C. (2005). Using Delegation as an Architecture for Adaptive Automation. Technical Report (No. AFRL-HE-WP-TP-2005-0029).

Overview:

A 3D model framework for adaptive automation, referred to as "Levels of Delegation", is described. Delegation implies that a subordinate is given the responsibility to perform a task (with its subtasks), along with some authority to decide how to perform that task, as well as access to resources with some authority to decide how to use them to perform the task. This paper describes the use of this framework within an application called Playbook.

The "Delegation Framework" has three dimensions, AAA: Level of Authority, Level of Abstraction and Level of Aggregation. These dimensions define a *Delegation Space* of human-automation relationships within which delegation occurs and can be characterized. The three scales must be used to specify four variables which define the delegation space: the level of abstraction and the level of authority on it, and the level of aggregation and the level of authority on it.

Below is a description of each dimension:

- *Levels of Authority*. Full, inform, override, approval, recommend, monitor, none.
- *Level of Abstraction.* Automation can have responsibility for higher- or lower-level tasks within the task hierarchy.
- *Level of Aggregation.* Identifies how much (and/or which type) of resource each actor is authorized to use.

Conclusions for IASs:

1. All three dimensions may not be available or relevant to every system or every interaction, but the authors advocate that the model needs to be rich enough to encompass them.

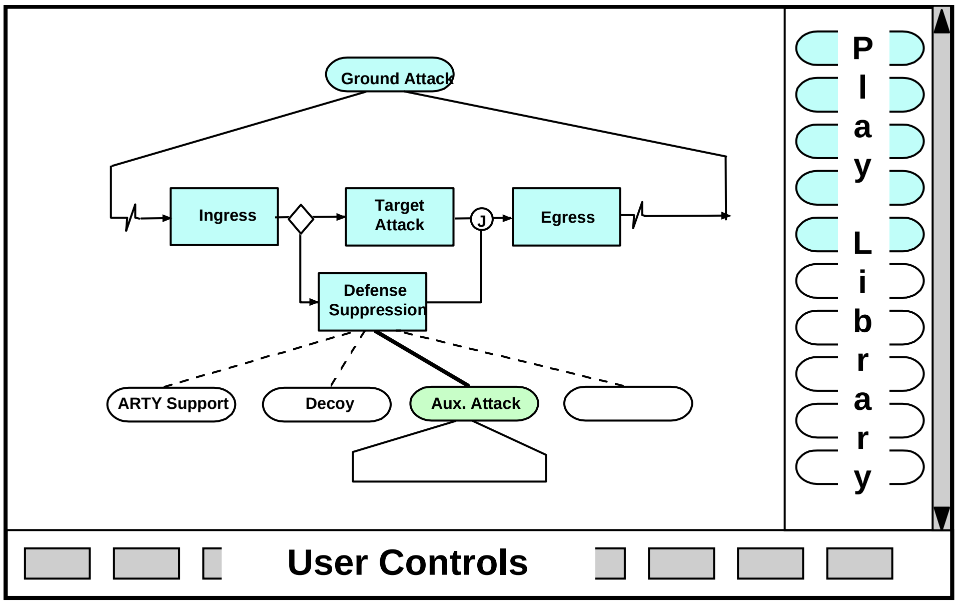

Figure 5: Playbook tasking interface for a military fast-jet ground attack mission.

3.3.4 Intelligent Classroom

Reference:

Franklin, D., Budzik, J., and Hammond, K. (2002). Plan-based Interfaces: Keeping Track of User Tasks and Acting to Cooperate. In IUI'02, January 13-16, 2002.

Overview:

This paper describes the concept of an Intelligent Classroom, which consists of a computer system that dynamically adapts to operator actions and inputs (gesture and voice) in a classroom environment (i.e., controls camera, automatic presentation slide-switcher). The algorithms are goal-based and driven by task recognition.

Intelligent Classroom: The IC is an automated lecture facility prototype that serves as its own audio/visual assistant. The operator (e.g., speaker), provides a presentation, and the Classroom watches and listens, and when appropriate, assists will provide assistance. The IC keeps track of various activities pursued by the speaker as well as its own activities in control of its various autonomous components.

The representation is used three ways to accomplish a goal: plan execution (execute a plan to achieve a goal), plan recognition (match the operator's actions to a set of known plans), and projection (follows the operator's plan and project future actions). A set of agents are used to monitor, recognize, and execute some plan to accomplish an operator goal.

ROLE	AGENT	AUTHORITY
ACQUIRE	-	-
ANALYZE/ PRESENT	-	-
DECIDE	💻 😐	💻 😐
ACT	💻	💻 😐

The system is based on the principle that the world is composed of a series of processes. A *process* is a single agent that executes a sequence of actions. It is composed of one or more discrete steps, each of which specifies a number of continuous actions and a number of discrete events. The processes are designed such that the Classroom can essentially use the same algorithm for executing a process that it used for observing the operator as the operator executes a process.

To alter the algorithm so that the Classroom can observe the operator and to follow along with the operator's plans, only a portion of the first step needs to be changed. Rather than performing the primitive actions that are a part of the step, the Classroom performs "observation" actions that complement the primitive actions.

The *Process manager* continually steps through its set of processes to keep them synchronized with the operator and revises the set of processes when required.

<u>Human-machine cooperation.</u> The operator, in executing part of a plan, expects the Classroom to do its part of the plan. A *plan* is a set of processes (often to be executed by a number of different agents) that when executed together successfully, accomplish some goal. In the Classroom, most plans have one process executed by the operator and one or two processes executed by the Classroom. This definition makes explicit the presence of other agents or exogenous events. In the Classroom, these plans attempt to express a common understanding of how a speaker and an audio/visual assistant interact.

<u>Conclusions:</u>

1. The more the system understands its operators and their tasks, the more useful the system will be.
2. The same techniques implemented in the Intelligent Classroom can be applied to a broad range of interactive applications. Refer to the paper for details on how to implement techniques.
3. The system should understand the operator's actions in the context of what it believes the operator is doing.
4. The ability to provide reason to the operator's activity is crucial to the implementation of an intelligent operator interface.
5. Plan generation and recognition are a promising means of adaptive automation and estimating pilot intent.
6. *Human-machine cooperation* can be achieved by allowing an operator, when executing a part of a plan, to expect a system to help in executing that part of the plan. A *plan* is a set of processes (often to be executed by a number of different agents) that when executed together successfully, accomplish some goal. Plans attempt to express a common understanding of how a speaker and an audio/visual assistant interact.

3.3.5 Lookout

Reference:

Horvitz, E. (1999). Principles of mixed-initiative user interfaces. In Proceedings of ACM Conference on Human Factors in Computing Systems (CHI'99), pp. 155-166.

Overview:

ROLE	AGENT	AUTHORITY
ACQUIRE	💻	💻
ANALYZE/ PRESENT	💻	💻 😐
DECIDE	💻	💻
ACT	💻	💻 😐

The authors review principles for directly manipulating automation and machine learning. These principles are highlighted in terms of the program called LookOut, an automated system for scheduling and meeting management.

LookOut: Is a program that automatically populates meeting request information based on an email message text in the body and subject.

Initiation of Lookout: The system can be initiated either by the human (clicking on icon or when prompted by the system) or automatically by the system based on a goal-based user model.

Direct manipulation. The operator communicates directly with the system through an animated widget.

User model. The user model is based on a "function of an inferred probability" that the operator has a goal of performing scheduling and calendaring operations.

Confidence estimation. The level of automation (initiation and action) is based on the system's uncertainty of the operator's goals which is based on the user model. The authors applied probabilistic models of an operator's goals. This is used to perform real-time inferences about the probability of alternate feasible goals by monitoring the current program context, and the operator's sequence of actions and choice of words used in a query. Bayesian network models were partially used to for a base for the confidence estimation algorithms.

Displaying automation uncertainty. The level of uncertainty about the operator's goals is displayed to the operator via visual indicators. At high levels of certainty, a character appears and indicates that it has readied a calendar view to show the operator or has created a tentative appointment before displaying the results. At lower levels of confidence, LookOut inquires about the operator's interest in either seeing the calendar or scheduling an appointment, depending on the system's analysis of the message being viewed.

Automated tasks. The decision of initiating automation is based on whether an agent believes it will have greater expected value than inaction for the operator, taking into consideration the costs, benefits and uncertainties in the operator's goals. Refer to the paper for implementation details.

Timing of prompting the initiation of automation. Automation and alerts of initiating automation is based on models of attention that consider the temporal pattern of an operator's focus of attention (timing model).

Machine learning. The system is designed to continue to learn from operators through caching operator behaviour with the system and by the operator specifying a policy for continual learning (e.g., set system to cache behaviour at particular times).

The authors recommend considering several critical factors when implementing integration of automated services with direct manipulation interfaces, as discussed below.

Conclusions for IASs:

1. *Uncertainty about an operator's goals can provide good input for inferring about an operator's intentions to perform an operation*. Computers are often uncertain about the goals and the current focus of attention of an operator. In many cases, systems can benefit by employing machinery for inferring the uncertainty about an operator's intentions and focus.
2. *Considering the status of an operator's attention in the timing of services***.** Systems (or agents) could use models of attention and consider the costs and benefits of deferring action to a time when the automation will be less distracting to the operator.
3. *Context-dependent automation*. Automated functions should be applied in a context-relevant manner based on uncertainty in an operator's goals and attention.
4. *The system should resolve uncertainties through a dialog with the operator*. If a system is uncertain about an operator's intentions, it should be able to engage in a dialog with the operator, considering the costs of potentially bothering an operator needlessly.
5. *Direct invocation and termination of automation should be provided***.** Efficient means should be provided which operators can directly invoke or terminate the automated services.
6. *Operators should have an efficient means to modify automation behavior***.** Agents should be designed so that operators can complete or refine an analysis provided by an agent.
7. *Agent-operator interaction should employ socially appropriate behaviors***.** An agent should be designed to behave in a way that matches social expectations.
8. *Recent operator interactions with the system should be saved***.** Systems should maintain a memory of recent interactions with operators and provide mechanisms that allow operators to make references to objects and services included in "shared" short-term experiences.
9. *Learning by observing operator behavior***.** Systems should be designed so that they continue to learn about an operator's goals and needs.

3.4 Intelligent Adaptive Hybrid Frameworks

This section reviews the following IAH frameworks:

- Cognitive Cockpit;
- Associate Systems Technology (Pilot's Associate and Rotorcraft Pilot's Associate);
- Cockpit Assistant System (CASSY); and,
- DRDC Toronto's Intelligent Adaptive Interface project for Uninhabited Aerial Vehicles.

3.4.1 Cognitive Cockpit (United Kingdom)

The Cognitive Cockpit was originally a large multi-disciplinary project funded by the Ministry of Defence (United Kingdom), and conducted at the Defence Evaluation and Research Agency (DERA), and then at QinetiQ, that is concerned with quantifying the effectiveness of pilot aiding designed to increase mission effectiveness and safety. The objective of the work was to specify the cognitive requirements for building the next generation of cockpit intelligent aiding systems for use in 2010-2015 time scales. Since 2000, the programme has continued under the funding of DARPA (United States), but has changed its emphasis to the control of multiple Uninhabited Combat Air Vehicles (UCAVs).

The goals of the Cognitive Cockpit will be achieved by developing an integrated system within a human-centred approach that keeps the operator in charge. This approach focuses on the pilot's requirement to be in control of the system and not be overwhelmed with system control information. Thus, the fundamental assumption of this research programme is to allow pilots, either airborne or on the ground controlling a UCAV, to concentrate their skills towards the relevant critical mission event, at the appropriate time, and to the appropriate level.

To provide a principled development of intelligent aiding with the required levels of pilot control, the project team established a guiding framework for "Cognitive Control" in the Cognitive Cockpit programme (Taylor, 1997; Taylor and Finnie, 1997; Taylor and Reising, 1999). This framework is based on the concepts and implications of Perceptual Control Theory (Powers, 1973; Taylor, 1997), and on the extant theory of Cognitive Control of Complex Systems (Rasmussen, 1986, 1993; Brehmer, 1992; and Hollnagel, 1997). By highlighting the importance of cognitive control, a more direct and systematic consideration of the cognitive engineering and control issues can be achieved. For example:

- The incorporation of the ability to track the operator's goals and plans (e.g. the difference between current and desired states) and to infer the intent of the operator;
- The use of abstraction hierarchies and system aggregation methods during task decomposition in order to determine important interactions and emergent properties within the knowledge base;
- The importance of information utility in the design process (e.g., a focus on the information used, rather than the resultant action);
- The importance of error diagnosis and rectification;
- The enhancement of system stability through the balance of feed-back (i.e., reactive) and feed-forward (i.e., proactive) control information;
- The recognition of differences in cognitive control strategies between skill, rule and knowledge-based levels of performance (Rasmussen, 1986);
- The incorporation of planning horizons (e.g., scrambled, opportunistic, tactical and strategic; Hollnagel, 1997) into cognitive control strategies; and,
- The use of intelligent aiding to critique operator performance and to prevent cognitive bias and other forms of human error.

The Cognitive Cockpit program brought together DERA's experience with systems for state monitoring pilot, capability in building Knowledge-Based Systems for decision support, and expertise in cognitive engineering and cockpit human factors integration. The Cognitive Cockpit comprises four functional modules:

- *Cognition Monitor (CogMon)*. This module is concerned with on-line analysis of the psychological, physiological and behavioural state of the pilot. Primary functions of this system include continuous monitoring of workload, and inferences about current attentional focus, ongoing cognition and intentions. It also seeks to detect dangerously high and low levels of arousal. Overall, this system provides information about the objective and subjective state of the pilot within a mission context. This information is used in order to optimise pilot performance and safety, and provides a basis for the implementation of pilot aiding;

- *Situation Assessment Support System.* This module is concerned with on-line mission analysis, aiding and support provided by intelligent software. This system is privy to the current mission, aircraft (e.g. heading, altitude and threat) and environmental status, and is also invested with extensive a priori tactical, operational and situational knowledge. Overall, this system provides information about the objective state of the aircraft within a mission context, and uses extensive knowledge-based systems in order to aid and support the pilot;

- *Tasking Interface Manager.* This module is concerned with on-line analysis of higher-order outputs from CogMon, SASS, as well as other aircraft systems. A central function for this system is maximisation of the goodness of fit between aircraft status, 'pilot-state' and tactical assessments provided by the SASS. These integrative functions mean that this system must be able to influence the prioritisation of tasks and, at a logical level, determine the means by which information is communicated to and from the pilot. Overall, this system allows pilots to manage their interaction with the cockpit automation, by way of control over the allocation of tasks to the automated systems; and,

- *Cognitive Cockpit (Cogpit).* This module is concerned with the specification and provision of a proof-of-concept simulation environment, including the form and function of a future cockpit in which Situation Assessment Support System, Cognition Monitor and Tasking Interface Manager modules will be implemented, tested and validated. In doing so, there is a requirement to utilise existing Human Factors analysis methods and Human-Computer Interaction guidelines.

Reference:

Taylor, R.M. (2001). Technologies for supporting human cognitive control. In Proceedings of the RTO HFM Specialists' Meeting on Human Factors in the 21st Century, Paris, France, 11-13 June 2001.

Overview:

ROLE	AGENT	AUTHORITY
ACQUIRE	💻 😐	😐
ANALYZE/ PRESENT	💻 😐	😐
DECIDE	💻 😐	😐
ACT	💻 😐	💻 😐

A proof-of-concept demonstration of Cognitive Cockpit technologies was undertaken by DERA that sought to couple on-monitoring of pilot functional state assessment, environment and mission plan. The aim was to allow the pilot in control of the aircraft, or the operator in control of an uninhabited air vehicle to "concentrate on their skills towards the relevant critical mission event, at the appropriate time, to the appropriate level". The framework that formed the basis of the Knowledge-Based system (roles), and adaptation (automation) was a feed-forward (operator and system), and feed backward (system) control task architecture. CommonKADS knowledge engineering methodology led to the development of six knowledge-level models: organisational, task, agent, knowledge, communication and design models. These models were used as a basis for the development of a multi-agent COGPIT system involving the following COGPIT agent architecture:

Cognition Monitor. Monitors pilot functional state (level of arousal and workload) which was based on the cognitive model.

Situation Assessor. Monitors environmental and aircraft state and recommends actions. It is based on the organization, task and knowledge models. Provides information about the state of the aircraft within the context of a mission and supports the decision-making process (considered a knowledge-based decision-support system).

Tasking Interface Manage. Implements adaptation (assignment of automation to the human or system agent) and is based on COGMON and SASS (i.e., maximum goodness of fit between aircraft status, pilot state and tactical assessments).

Pilot Authorizing and Control Tasks (PACT). PACT is operator initiated decision aiding and implementing automation (pilot control of tasks). Based on the roles/stages of information processing.

Dynamic adaptive interface. Automatically assigns roles to the system or operator according to operator agreed, context-sensitive adaptive rules.

The aim of the COGPIT architecture was to increase system adaptiveness by enabling changes to be made to the mission plan in response to changes in the situation. The COGPIT monitored three aspects of the situation: *the pilot* to take account of his physiological and cognitive state, *the environment*, both external to the aircraft and the aircraft systems, and *the mission plan* to indicate current and future pilot actions. Information from monitoring the environment, the mission plan and the pilot provided inputs into the processes of re-planning the mission, automating tasks, deciding automation and configuring the cockpit. These processes then provided input into updating the mission plan.

Conclusions for IASs:

1. IAHs should be based on an Operator-Centred Design (OCD) process.
2. CommonKADS models proved to be a useful knowledge acquisition technique for the development of the SASS model. The PC PAC and MetaPAC toolsets were essential in supporting the acquisition and modeling processes.
3. Knowledge acquisition techniques, based on a Goals, Means Task Analysis methodology, were necessary for developing the task-based TIM, and particularly useful for on-line KBS support for pilot re-planning tasks,
4. Timing is critical for contextual KBS advice to be effective.
5. Intelligent aiding can be successfully implemented if it has a well-developed multi-system architecture based on an operator-centred design methodology.

Reference:

Taylor, R. M., Bonner. M. C., Dickson, B., Howells, H., Miller, C. A., Milton, N., Pleydell-Pearce, K., Shadbolt, N., Tennison, J., & Whitecross (2003). Cognitive Cockpit Engineering: Coupling Functional State Assessment, Task Knowledge Management, and Decision Support for Context-Sensitive Aiding. In M. D. McNeese & M. Vidulich (Eds.). Cognitive systems engineering in military aviation environments: Avoiding cogminutia fragmentosa! (pp. 253-312). Human Systems Information Analysis Center State-of-the-art Report 02-01. Wright-Patterson Air Force Base, OH: Human Systems Information Analysis Center.

Overview:

Describes the Cognitive Cockpit research program that seeks to couple pilot functional state assessment, knowledge-based systems for situation assessment, and decision support, with concepts and technologies for adaptive automation and cockpit adaptive interfaces. The authors advocate for a functional integration approach to system development where several functional components can collectively perform many of the same behaviours as the pilot, and of cognitive control between the pilot and the intelligent aiding systems.

The authors also present a summary of the methods, tools, and techniques used on the COGPIT project in the phases of the development of the COGPIT systems, including cognitive engineering (see Table 8.6 on p. 305). Work to date has provided mission-based functional decomposition, cognitive task analysis, knowledge acquisition and modeling, interface prototyping, initial proof-of-concept simulation, and cognitive story-board evaluation.

To determine required levels of pilot control, the authors based their framework on concepts and implications of Perceptual Control Theory and the theory of cognitive control of complex systems; this work was also influenced by the Information Processing (IP) theory load under time pressure and DERA's work on cognitive streaming.

COGMON. In order to provide a real-time model about the cognitive-affective state of a pilot, four principle sources of information are available: physiology, behaviour, subjective and context states.

- **Physiological Measures:** Measures include heart rate, respiration rate, electromyogram, electrodermal activity, skin temperature, electro-EEG, eye-movement activity and blink rate. Since many physiological measures are correlated, COGMON uses various mathematical tools aimed at uncoupling correlations between its incoming physiological variables.
- **Behavioural Measures:** Behavioural data provide information that can be used to make inferences about cognitive states. COGMON uses a pre-existing database and probability theories about which combination of procedures attempt to infer pilot intent. It is also contextually sensitive.
- **Subjective Measures:** These measures are used in to get explicit feedback from the pilot (1) during the task and (2) during system development.
- **Contextual Measures:** to provide COGMON a context in which to interpret the incoming information. Some of these measures include ambient noise, luminance, aircraft parameters, etc.

Operator customization. COGMON has a database that holds information about each operator to provide operator specific assistance.

COGMON architecture includes individual components that can also function in isolation which can be adapted for other systems.

SASS, the Situation Assessor, handles situation assessment on a task-by-task basis with no separate module or agent to perform the assessment of the situation. This approach allows the system to assess the situation within the context of the task being performed and not as a separate activity (similar to what expert human operators do). CommonKADS was used to develop this module.

TIM, the overall architecture of an adaptive cockpit involves 12 functions, with a flow of information and control across the functions (see p289 for chart). This module is based on a “Shared Task Model” to code, track and dynamically modify operator’s goals and plans. This is a “delegation module” based on Playbook principles. The task model used for COGPIT uses three task categories: generic, mission specific, and specific tasks.

<u>Conclusions for IASs</u>:

1. The authors advocate for a functional integration approach to system development where several functional components can collectively perform many of the same behaviours as the pilot and of cognitive control between the pilot and the intelligent aiding systems.
2. The COGPIT project demonstrated that functional analysis of cognitive work can be used to provide the foundations for the development and implementation of cognitive technologies.
3. It was also demonstrated that cognitive work analysis seems particularly promising in providing a broad set of models and tools for human systems analysis, based on a high-level functional analysis.
4. On-line operator functional state assessment appears to be feasible with current computing power and may be useful to provide information for the dynamic allocation of automation.
5. Knowledge engineering methodology can be used to provide on-line knowledge-based systems to support operator re-planning tasks.
6. IAH system OMIs, tasks, and automation can be managed by a tasking interface system based on a shared task model.

Reference:

Bonner, M.C., Taylor, R. M., Fletcher, K., and Miller, C. (2000). Adaptive automation and decision aiding in the military fast-jet domain. *In proceedings of the conference on Human Performance, Situation Awareness and Automation: User centred design for the new Millennium*.

Overview:

This paper presents the operation and technical development of the Tasking Interface Manager component of the Cognitive Cockpit. The TIM utilised input from the Situation Assessment Support System and the Cognition Monitor to adaptively present information and adaptively automate tasks according to the situational context and the pilot's internal state. The goal of TIM is to reduce task and cognitive load on aircrew. The main feature of the TIM is a shared mental model, the ability to track goals, plans and tasks, and the ability to communicate intent about the mission plan. The objective of the TIM is to allow aircrew to retain executive control of aircraft and mission parameters in conjunction with the assistance of adaptive automation.

TIM involves the following characteristics:

1. *A shared task model:* The TIM was based on a task model to help encode, track and model the operator's goals and plans and ensure that they are highly-coordinated with the system. Three task categories were used in the COGPIT framework: 1) *task generic* (tasks that never change); 2) *mission specific* (tasks that change with the mission but are constant within the mission); and 3) *task specific* (tasks which change within the mission).
2. *Task Tracking Capabilities:* A need for a Full Goal Plan Tracking (GPT) capability was identified during the knowledge acquisition process. It was realized that the system should be able to track any task undertaken by the pilot. Implementation of this system, however, is currently limited by funding resources (as of year 2000).
3. *Communication about Intent:* The goal of this approach is to allow the human operator to communicate tasking instructions (i.e., delegated automation) in the form of desired goals, tasks, partial plans or constraints. These tasking instructions should be developed in accordance with task structures defined in the shared task model.
4. *Adaptive Automation:* Adaptive automation is controlled by the Plot Authorization and Control of Tasks system, an operator-initiated allocation of automation (pilot control of tasks/automation). The allocation of automation is defined by the level of authority the pilot has over the initiation of automation and the level of system autonomy.

Conclusions for IASs:

1. The authors declare that tasks (or functions) need to be continuously tracked according to the state of the mission plan in order for the system to determine the information and automation needs of the operator.
2. To maintain operator situational awareness, tasks should be tracked explicitly (e.g., by asking the operator for input or making the system state visible to the operator), especially in high-criticality environments.
3. The allocation of tasks to the system should be controlled by the operator. This allocation can

be controlled by the operator in several ways: 1) pre-set operator preferred defaults; 2) operator selection during pre-mission planning; 3) allocation by the operator during in-mission re-planning; and 4) automatically allocated according to operator agreed, context-sensitive adaptive rules.

4. The automation of tasks and their allocation can be provided by a tasking interface system based on a shared task model. The use of a tasking interface can allow an operator executive control of the system and mission while enabling almost full autonomy for an aiding agent.

Reference:

Taylor, R. M. (1998). The human-electronic crew: Human-computer collaborative team working. Proceedings of the 1st NATO RTO Human Factors and Medical Panel Symposium on Collaborative Crew Performance in Complex Operational Systems, Edinburgh, UK, 20-22 April 1998.

Overview:

This paper describes the concept of Human-Electronic Crew (HEC) teamwork, whereby the electronic crew member (the electronic support system) acts as an associate or an assistant, sharing responsibility, authority and autonomy over many cockpit tasks. Various methods are suggested for ensuring that the relationship between the operator and the system is flexible and adaptive including: in-flight situation assessment and re-planning (of goals), cognitive modelling, human intent inferencing and error recognition (tracking of tasks), and the use of complex knowledge engineering and reasoning logic processes.

Intelligent aiding systems can be distinguished in terms of three main types (all three types can and should work/co-operate together):

- *Assistants:* perform specific tasks when asked, using basic task and situational knowledge (e.g., automation of a task such as auto-pilot).
- *Associates:* recognize that the operator needs assistance, using complex task and situational knowledge, and basic operator co-ordination knowledge (i.e., allocates automation based on an operator and situational model)
- *Coaches:* both aids and instructs to assist the operator better, using complex task, situation, operator and co-ordination knowledge (e.g., decision aid; dynamic function allocation).

This paper compared the Co-Pilote Electronic, CASSY/CAMMA and Pilot's Associate project in implementation strategy.

1. Differences in approach lie in how the automation is initiated (who has control) between CE and PA. The CE approach emphasizes pilot involvement and judgment (pilot control) whereas the PA objective is a full associate relationship (sharing of control).
2. CE and CAMMA projects are more technically realistic (it is difficult to implement a full associate relationship because the system is expected to perform at the same level as the human where humans can make leaps of abstraction and intuition, producing new solutions to novel problems).

Conclusions for IASs:

1. The authors advocate that it is imperative to understand the operator's role within the system to determine the appropriate system support for that role. The analysis of the operator's role can guide the system design.
2. A full associate system is more technically difficult to implement (e.g., PA project) because the system is expected to perform at the same level of abstraction as the human operator.
3. Intelligent aiding systems (e.g., full associate system) should provide assistance with the basic functions of assessment, planning, co-ordinating and acting (to mimic human information processing and problem-solving abilities).
4. Functional architectures are a good way to implement IAHs that support strong interactions and tight integration. That is, the behaviours required by the domains (e.g., tasks) are shared between the system and the human across the functional components.
5. In order to support an associate relationship with the system, the authors claim that function allocation should be flexible and dynamic, driven more by the situation and context, than by the preservation of a sole sources of control authority (unlike the CAMMY and CE project that are driven by pilot control).
6. Operator trust is enhanced by IAH system consistency and correctness (e.g., decisions and actions are consistent and predictable).
7. The plan-goal graph (PGG) modelling approach was developed to address the problem of intent referencing and used in the HEC model as a means to predict pilot intent. Intent recognition is achieved by differentiating the goals from the behaviour of the operator.
8. Operator errors with increased risk of severe consequences (especially without corrective action) should require assertive intervention and action aiding by the system (e.g., auto-pilot is automatically turned on when the pilot loses consciousness).
9. System transparency is needed to maintain awareness of system functioning (system state; e.g., when automation is turned on or off) and a sense of operator control.
10. The system should conform to the pilots' mental model. A mental model is a representation formed by an operator of a system and/or task and is based on previous experience and current observation. This provides a basis for the operators understanding of system functionality which can influence their performance on tasks.

Reference:

Taylor, R. M. and Finnie, S. E. (1997). The Cognitive Cockpit: Adaptation and control of complex systems. Proceedings of the 4th Electronic Crew Conference, Kreuth, Germany, 23-26 September 1997.

Overview:

Considers the relevance of control theory as a broad framework for Human-Electronic Crew teamwork in dealing with uncertainty in dynamic situations. It examines possible "Cognitive Cockpit" architectures for future HEC systems, which adapt to both control feedback and feed forward requirements, encompassing the uncertainty in dynamic situations.

- The authors found that control problems arising from poor mode awareness are commonly reported with complex automated systems.

- There is evidence that compliance (i.e., over-reliance) to automation can occur if the automation is not clear when and how it is applied by the IAH system (i.e., the mode of system state is not transparent).
- The aim of the COGPIT work is to find appropriate blend of feed forward and feedback information for supporting the intentions of commanders and operators that enable them to be in control of, rather than controlled by, the system.

Conclusions for IASs:

1. The authors have concluded that the operator should have a means of monitoring system functioning (e.g., checking and direction), especially in uncertain and highly-complex environments.
2. The operator should be actively involved in generating plans and determining execution triggers of automation.
3. Automated support (allocation of tasks to the system) can be structured according Rasmussen's Skills, Rule and Knowledge Framework (cognitive systems engineering). It was found that this approach can highlight opportunities for the dynamic allocation of functions to the system (i.e., initiation of automation).
4. System feed-forward and feedback information can be provided to the operator based on the perceptual control model (i.e. IMPACT). That is, intelligent aiding should be designed to support pilot desires or intentionality (i.e., goal-based support).

3.4.2 Associate Systems Technology

A major hurdle in the development of IAHs is the requirement for accurate monitoring of the physical and cognitive state of the operator. Such monitoring is required to ensure that the autonomous changes in automation level or OMI adaptation being executed by the system are appropriate to maintain optimised operator performance and information processing. Although a number of solutions are currently in development, there are currently no mature means of producing such monitoring. Further progress in the field of operator state monitoring will be required if IAHs are to be realised in war-fighting domains.

Due to the difficulty in realising effective adaptation, developers have attempted to avoid the requirement for adaptation based on the physical and cognitive state of the operator (although some small elements of adaptation may exist where achievable) and instead focused on providing mission planning and decision making support in the form of co-operative, intelligent sub-systems acting in a team-based manner with the operator. These developments have typically been characterised as Associate Systems Technology (AST), exemplified by the US Pilot's Associate and Rotorcraft Pilot's Associate programmes.

Associate System Technology, otherwise known as integrated real-time intelligent systems, provides intelligent decision aiding. The intention is not to replace aircrew, but to organise uncertain or conflicting information through data fusion and to provide data interpretation, hypothesis formulation, planning and decision aiding to the operator. In other words, the system is not making decisions; instead it is doing some of the ground-work so that the operator can choose the best solution in any given situation.

An associate system is characterised by several attributes. An associate knows how to help without being told by the operator. An associate shares a sense of purpose with the operator (i.e., common intent) and formulates plans to achieve the joint purpose. An associate actively assesses the world and communicates important aspects of the situation and response options to the operator. An associate actively aids task execution as authorised by the operator. It can contribute greatly to the operator's ability to see and comprehend the battlefield in all conditions, a rapidly collect, synthesise, and disseminate battlefield information, and take immediate and effective actions.

Associate Systems typically have two components:

- *Cognitive Decision Aiding*. The Cognitive Decision Aiding Sub-system (CDAS) performs situation assessment, planning, and cockpit information management. Cognitive decision aiding is applied at the crew level to augment the crew's decision making process (i.e., an en-route mission change or actions-on-contact with the enemy). Unique crew aiding behaviours partition the tasks between the crew and the CDAS so to best utilise the advantages of the human crew member and the computer planner assessor. Crew selectable levels of the associate functioning are also possible.

- *Crew Intent Estimation*. The purpose of Crew Intent Estimation (CIE) is to ensure that the operator is always in charge of the associate system's functioning, so that the system is never pursuing old or counter-productive behaviours. It tracks operator behaviour and provides co-ordinating information to planners and assessors attempting to support the operator. For example, there are specific mechanisms for resolving actions that can have multiple interpretations, miscues and confusions between what the associate thinks the operator is doing versus what the CIE just determined.

3.4.2.1 Pilot's Associate (United States)

The Pilot's Associate program was part of a $40 million effort by Lockheed (1986-1992) to mobilise artificial intelligence technology for real world operational problems in the United States Department of Defence. The Pilot's Associate was to be an "electronic back-seater", an aid to the pilot that could monitor the current external situation, assess threats, and plan reactions to events, thus demonstrating the effectiveness of integrated, real-time intelligent systems in the air combat domain. This project provided the first associate system capable of operating in close co-operation with its human counterpart. Although the Pilot's Associate program ended in 1992, it has had a significant impact (e.g., parts of the Pilot's Associate have been incorporated into the avionics of the F-22).

Between 1990 and1992, Honeywell developed the Learning System Pilot Aiding (LSPA) project. The goal of the LSPA project was to demonstrate that explanation-based learning, a type of machine learning that utilizes a worked example of a problem as a problem-solving method, would be effective for automatically generating knowledge bases for Pilot's Associate from single instances of observed pilot behaviour. At its conclusion, LSPA showed successfully that finished knowledge bases for tactical planning and for information management could be created directly from time histories of pilot behaviour in a simulator.

3.4.2.2 *Rotorcraft Pilot's Associate (United States)*

The Rotorcraft Pilot's Associate advanced technology demonstration programme started in June 1993 with conceptual design studies. Manned simulation and flight test evaluations were completed in 1998. The objective of the RPA programme was to:

- Apply AI and state-of-the-art computing technologies to manage and integrate next generation mission equipment and battlefield information; and,
- Enhance the lethality, survivability, and mission effectiveness of combat helicopters.

The RPA technology demonstration was intended to enhance crew performance and mission execution by applying associate system technology to the cockpit to intelligently manage the sub-systems as well as the information flow to and from the crew. Operationally, the RPA aims to free the crew to execute their mission more effectively by managing the myriad of significant and insignificant data from the sensors. RPA attempts to anticipate crew needs based on mission context and provide the right information at the right time, and when authorised, will take the initiative to actively aid the crew and execute tasks.

Functionally, RPA consists of a Cognitive Decision Aiding System (CDAS) and data fusion. CDAS has three basic interdependent modules: internal and external situation assessors; planning modules; and a cockpit information manager. The core architecture contains CDAS, controls and displays processors for each crew-station, interfaces to a suite of advanced mission equipment sub-systems, a data distribution system, and data fusion. The output of data fusion is used to assess the battlefield in terms of threats, targets, obstacles, and friendly troops. Entity groups and relationships are identified in order to recognise events that pose near term danger. Threat capabilities and intentions are estimated and the possible impacts on mission plans are considered. Information is disseminated to the team, Tactical Operations Centre, and intelligence networks as appropriate. CDAS prioritises and co-ordinates target attack, predicts success probability considering team co-ordination, and monitors progress.

In addition, six onboard planners use the information produced by data fusion and assessment sub-systems to aid the crew in reacting quickly and efficiently to changing and unexpected events that occur during the mission. These planners are:

- *Survivability planner*. Continuously updates countermeasures and evasive manoeuvre recommendations. Intelligently configures mission equipment such as jammers or chaff dispensers and fine-tunes flight envelopes to minimise signature to known and probable threats;
- *Sensor planner*. Contextually optimises sensor settings such as field-of-view or frequency band selection, employs multiple sensors synergistically, co-ordinates the team's use of sensors by allocating coverage areas and performing multi-ship data correlation, and compensates for sensor equipment failure and degradation;
- *Communications planner.* Automates routine calls, radio selection and keying in compliance with standard operating procedures. It adapts for communication equipment failures, current environmental conditions, and changing sector boundaries. Also recommends the optimum time and location for calls, estimates the probability of reception and intercept and co-ordinates team radio calls;

- *Attack planner*. Selects priority fire zones and no-fire zones, co-ordinates target scans and target designations, recommends appropriate weapons using onboard weapons models, automates assistance for running fires, recommends engagement areas and battle positions, and co-ordinates and synchronises the attack to minimise enemy response;
- *Reconnaissance planner*. *Develops* a co-ordinated, multi-platform effort to safely and efficiently perform zone, route or area reconnaissance. Also maximises the information collected and minimises the likelihood of ownship detection; and,
- *Route planner*. Re-plans flight routes over large areas with high resolution. Factors such as distance, time, fuel, flight regime, and known probable moving and stationary threats are considered.

Reference:

Miller, C.A. and Dorneich, M.C. (2006). From Associate Systems to Augmented Cognition 25 Years of User Adaptation in High Criticality Systems. Poster presented at the Augmented Cognition conference, October 2006, San Francisco.

Overview:

In the 1980's, the U.S. Air Force initiated the development of a human-adaptive, information, and automation management technology known as the "Pilot's Associate".

ROLE	AGENT	AUTHORITY
ACQUIRE	💻 ☺	💻 ☺
ANALYZE/ PRESENT	💻	💻
DECIDE	💻	💻 ☺
ACT	💻 ☺	☺

What is it? PA, and all of the subsequent associate systems, consisted of an integrated suite of intelligent subsystems that were designed to share (among themselves and with the pilot) a common understanding of the mission, the current state of the world, the aircraft and the pilot. Associate systems were designed to use the shared knowledge to plan and suggest courses of action, and to adapt cockpit information displays and the behaviour of aircraft automation.

Automation of tasks: Tasks are automated only in line with the operator's goals and, whenever feasible, to be authorized by the operator. Operator control of the automation was established either during the mission, immediately prior to execution of automation, or pre-mission, in a pre-authorization mode.

Lessons Learned from PA efforts: Associate systems were and are the predecessors of augmented cognition (AugCog) technologies. While there are many similarities between PA and AugCog systems, there are also some many differences:

- Associate systems leave the pilot "in charge" which is extremely important in high criticality domains. To increase the chance of operator acceptance, it is important to consider that the operator should be kept in the loop. The authors claim that if the pilot is responsible for the actions of the aircraft, then the pilot must be the final authority of the aircraft's actions.
- All components (e.g., sensors, information fusion technologies, and interfaces) should be co-developed and evaluated in concert.
- A task-based framework was an effective way to coordinate a variety of processes (or subsystems) and minimize the costs of revising or extending them.
- Personification (or customization) is out of place in high criticality domains (and possibly other

domains, as HCI).

- OMI design proved to be an important component of the associate system. It was often found that the OMI will highlight anything that is wrong with any module, and errors in the design of the OMI will make all other aspects of the associate less effective.
- Adaptation of systems to individual differences and operator expectations (but not customization) can have large payoffs for fitting a system to an operator's needs and capabilities.

Conclusions for IASs:

Several "Lessons Learned" from the PA efforts were outlined in this paper, which have implications for the development of IA systems (see Lesson learned from PA efforts above):

1. *Importance of operator acceptance and, therefore, importance of keeping human "in charge".* The authors advocate migrating control to a supervisory level (where the human varies the amount and level of automation) and that the system should not rely too heavily on inferred operator state or intent. This can increase human out-of-the-loop problems.
2. *Importance of co-development and progressive testing*: Development efforts and individual technologies should be co-developed and used in collaboration, which can aid the development of an overall system. For instance, the development of neurophysiological sensors or "meters", other means of assessing operator state, and the development of methods for "augmenting" cognition through information display technologies need to be co-developed and evaluated in concert.
3. *Benefits of an explicit, integrative framework (task model).* Knowledge of the task context can help develop systems that manage task demand and increase operator performance.
4. *Operator-machine interactions.* More effective means of interactions between the operator and the system may be achieved if the designer approaches an intelligent system as a "personified agent" whose goal it is to aid the operator and to recognize that the operator might have feelings or attitudes.
5. *Importance of interface and interaction design.* A system, especially for a high criticality domain, should be designed with a system failure in mind. The authors provide some methods that can accomplish this: give the operator the ability to override and turn off the technology; allow the operator to explicitly authorize a display modification, to be notified of pending changes, to be notified of executed changes, and to rapidly return to a previous display state.
6. *Importance of learning, especially individuation.* Recording individual performance effects could serve to provide a powerful means of adapting system behaviour to the individual.

Reference:



Geddes, N.D., and Shalin, V.L. (1997). *Intelligent decision aiding for aviation.* Technical Report (No. ISSN 1402-7585). Prepared for Linkoping Institute of Technology, Linkpoping, Sweden.

Overview:

Intelligent decision aiding technologies (adaptive systems and automation) are reviewed in the context of the aviation domain. This report explores issues of system architecture, development and integration methods, and approaches to the test and evaluation of large-scale intelligent aiding systems. The focus is based on the Pilot's Associate program. The following briefly describes the development strategies used to develop IAI systems:

- *Human-Centered Design (HMD) perspective:* This perspective determined that the role of the human in the system is based on an operational philosophy. It identified what types of roles humans should play in the system (e.g., as authority and agent).
- *Design Representations:* The use of Intelligent Object-Oriented Design (IOOD) is a series of steps that is well suited to transform requirements (e.g., system, operator, organization) to more abstract views of objects (refer to pages 65-68 for details on this process).
- *Iterative Design Process:* This process recognizes the need for feedback into the design and requirements process to ensure that the design of the system evolves. This process outlines a series of prototyping cycles which is a common means of organizing iterative development.
- *Application of development tools:* It was found that an iterative development is most productive when supported by a set of management, design and testing tools (e.g., Plan Goal Graph Tool, Display Analyst)

<u>Conclusions for IASs</u>:

1. An HMD process is an effective approach to identify the types of roles humans should play in the system (i.e., as agents and authority over the initiation of automation).
2. The authors found that knowledge-based systems, such as intelligent adaptive systems, require more elaboration at higher levels of abstraction (e.g., plan-goal graphs; abstract processes, behaviours and use case templates). This can be achieved through IOOD. Object-oriented languages are well suited to transform requirements and support the development of IAH systems.
3. An iterative design process is a good way to enable the design and requirements process. This approach ensures that the system is verified against its design and validated against its requirements.
4. Complex intelligent adaptive systems require many agents and frameworks (i.e., operational knowledge representations). Interaction protocols can be used to ensure that the system operates as a whole.
5. There are now a large number of well-developed reasoning algorithms and operational knowledge representations. While a wealth of processes (i.e., algorithms) and representations is often necessary for complex systems, the authors are careful to indicate that the system should take the form that best suits the process desired.
6. The authors have noted that the development process requires tool support (e.g., PGG) but that the tools presently available (as of 1997) fall short for knowledge-based systems. System designers must therefore anticipate the need to develop tools along with the product.
7. By starting with a core system and an open architecture, IA systems can evolve into broader and more powerful support systems. For instance, rather than starting in the cockpit of a helicopter of single jet seat fighter, a better starting place may be within the mission crew.

Reference:

Miller, C. and Hannen, M. (1998). User acceptance of an intelligent user interface: A rotorcraft pilot's associate example. In M. T. Maybury (Ed.). Proceedings of the 4th International conference on intelligent user interfaces (pp. 109-116). New York, NY: ACM Press.

Overview:

This paper details the high level architecture of the Cockpit Information Manager (of the RPA). It emphasizes how pilot behaviours are monitored, crew intent is estimated, symbols are selected and de-cluttered, windows are located, and the automated pan and zoom, and allocation of tasks are implemented.

Cockpit Information Manager (CIM) Architecture

- The UI is primarily task-based.
- This module is responsible for determining the current and near-future tasks of the crew and then adjusting the cockpit configuration to meet task needs.
- Tasks are allocated to agents (human and machine) through this interface through functions that are required for specific tasks (full associate relationship).
- Task and context information are provided to the CIM by the Task Network and Context Model.
- A “Crew Intent Estimator” is used to interpret pilot actions and world events against mission plans in the “Task Network”, which determines whether the pilots are following mission model or are attempting alternate plans or goals (this is similar to the DIAMAnD, DRDC and Intelligent Classroom frameworks that use plan generation and recognition).
- CIM maintains an operator profile (e.g., violations in pilot expectations, information needs, etc).
- CIM performs six primary activities observable by the pilot: intent estimation, task allocation, page selection, symbol selection/de-clutter, window placement and pan and zoom.

Conclusions for IASs:

1. A full associate relationship approach is taken by the RPA program for providing system assistance.
2. This approach requires that pilot intent and error recognition are monitored and estimated to provide context appropriate assistance (this is done with a Crew Intent Estimator).
3. A World State or “Context” Model is used to determine context.
4. A task and goal-based approach in the form of a Task Network is used to estimate pilot intent and error recognition with pre-define tasks/goals.
5. An operator profile is used to determine pilot expectations, their information needs, etc.
6. Preliminary results from a simulation test found that the CIM behaviours are contributing to perceived pilot effectiveness, reducing workload and are gaining pilot acceptance.

3.4.3 Cockpit Assistant System (CASSY) (Germany)

Reference:

Gerlach, M. and Onken, R. (1995). CASSY- The electronic part of the human-electronic crew. Proceedings of the 3rd international workshop on human-computer teamwork (Human-Electronic Crew: Can we trust the team?). Cambridge, UK, 27-30 September 1994.

Overview:

ROLE	AGENT	AUTHORITY
ACQUIRE	💻	💻 😐
ANALYZE/ PRESENT	💻	💻 😐
DECIDE	💻	💻 😐
ACT	💻 😐	😐

The knowledge-based commercial aircraft Cockpit Assistant System is a civil aviation cockpit assistant project developed as an intelligent decision aid. It emphasises pilot assistance through situation assessment and re-planning in flight. Situation-dependent assistance with flight planning is guided by a normative pilot model, goal conflict, pilot intent, and error recognition functions. It also aids in the execution of pilot selected functions.

CASSY is composed of several situation assessment modules that interface with the flight crew, the aircraft, and air traffic control (ATC), which all collaborate with each other:

- *Automatic Flight Planning.* This module generates a complete global flight plan based on its knowledge of mission goal, ATC instructions, aircraft systems status and environmental data. The flight plan(s) is presented as a proposal which the crew accepts or modifies, and once chosen, serves as a knowledge source for other CASSY modules.
- *Piloting Expert.* Uses the valid flight plan and processes the crew model to generate necessary crew actions.
- *Pilot Intent and Error Recognition.* The expected crew actions are compared with the shown behaviour of the crew. Crew actions are derived indirectly by interpreting aircraft data. If given tolerances are violated, the crew will be informed by hints and warnings and the detected mistake is alerted to the pilots.
- *Monitoring.* Enable the system to recognize and interpret current situations (flight status, environment, and systems).
- *Execution Aid.* Automation of tasks which are controlled by the crew.

The Dialogue Manager: This is the OMI that enables the operator to interact with the system via a graphic/alphanumeric display and speech recognition.

This paper describes the results of the CASSY flight tests. The flight tests evaluated flight management KBS for rerouting of civil aircraft. Results of flight test were:

- *System performance:* Correct expected pilot actions were generated and pilot errors were detected and appropriate warnings issued; and
- *Operator acceptance*: CASSY was well accepted; autonomous flight plan appreciated, warning and hints considered justified.

The CASSY project is a successful real-time demonstration of an intelligent adaptive system implemented in a real and not virtual environment. This project led to the CAMMA military cockpit assistant project.

Conclusions for IASs:

1. Flight tests proved that intelligent decision aiding is feasibly possible and well accepted by operators.
2. The CASSY project is a successful real-time demonstration of an intelligent adaptive system implemented in a real and not virtual environment.
3. Situation assessment is an important feature of a successful intelligent system.

Reference:

Wittig, T. and Onken, R. (1992). Pilot intent and error recognition as part of a knowledge based cockpit assistant. Proceedings of the AGARD conference on Combat automation for airborne weapon systems: Man/machine interface trends and technologies, Edinburgh, UK, 19-22 October 1992.

Overview:

This paper describes the concept and functionality of the Cockpit Assistant System; including pilot intent and error recognition. Evaluation of CASSY in a flight simulator is also described.

The Pilot Intent and Error Recognition (PIER) module supports the pilot crew with regard to the monitoring and planning task, and provides assistance for a number of plan execution functions. During the whole flight, the module monitors pilot activities and the flight status in order to detect deviations from the actual flight plan immediately. The current flight situation is evaluated, and pilot behaviour is analyzed over a certain period of time and through either pilot intent or error. Pilot errors lead to warning messages and modifications of the flight plan. The module is mainly performed by use of an “inference algorithm” based on known intent hypotheses.

PIER is composed of the following structure: situation, pilot behaviour and pilot situation interpretation; determinant of pilot action sequence, classification of crew intent; final intent and error inference.

Conclusions for IASs:

1. Operator intent and error recognition can be an effective means of providing adaptive assistance.
2. Uncertainties can be evaluated using certainty factors (probabilistic reasoning such as Bayes’ Theorem).
3. Algorithms based on a-priori probabilities for possible hypotheses have proven useful for recognizing and estimating operator intent. The probabilities can be modified with respect to operator actions.

3.4.4 DRDC-Toronto IAI UAV Project (Canada)

<u>Reference</u>:

Hou, M. Kobierski, R., and Herdman, C. (2006) Design and Evaluation of Intelligent Adaptive Operator Interfaces for the Control of Multiple UAVs. Proceedings of the RTO Human Factors and Medicine Panel Symposium. Biaritz, France.

<u>Overview:</u>

ROLE	AGENT	AUTHORITY
ACQUIRE	💻 😐	💻 😐
ANALYZE/ PRESENT	💻	💻
DECIDE	💻 😐	💻 😐
ACT	💻 😐	💻 😐

This paper reports on a multi-phase project to investigate the potential of artificial intelligence for the control of multiple UAVs. These three phases include IAI concept development, interface prototyping, and experimentation. Human-in-the-loop trials in a realistic mission scenario were conducted to examine the performance model developed by DRDC.

Experimentation: Two modes were investigated. The first mode required operators to use a conventional interface to control the UAVs and the second mode included interface automation that used an IAI. The difference between mission activities with and without automation was examined.

IAI Experimental Environment: The trails were conducted in a synthetic environment. Three control consoles, consistent with the UAV crew position, were setup to replicate CP140 tactical compartment multifunction workstations. Workstations were designed to communicate with virtual UAVs through fully functional real world software interfaces. Each member of the UAV crew was provided with their own workstation, which consisted of a main display screen, a keyboard, a programmable entry panel, a trackball/mouse, and a joystick.

The UAV sensor operator's primary display was designed for providing the information necessary to manage and extract information from a large number of sensors. The main display area was highly customizable, allowing the operator the flexibility in creating layouts for the display of sensor data and in switching between those layouts.

The *IAI agents* were designed to follow a defined sequence as follows:

<u>Step 1:</u> *Gather status information* about all active UAVs, the tracks pertinent to those UAVs and the current display configuration.

<u>Step 2:</u> *Analyse the information* with respect to pre-defined rules and determine which events have occurred.

<u>Step 3:</u> *Prioritize the events* with respect to pre-defined prioritization rules.

<u>Step 4:</u> *Execute pre-defined tasks* for each identified event following the order of prioritization.

Six software agents were designed and implemented to provide the following adaptive aiding: route planning, route following, screen management, inter-crew communication, sensor management, and data link monitoring.

Results. Results indicate that operators performed more effectively when the IAI multi-agent system was selected ON. When IAI was ON, completion time for critical task sequences were shortened, less tasks were shed, the UAV trajectory scores were better and much less time was spent in the no-fly areas. In addition, operators' overall SA was improved and overall workload was reduced as well.

Several recommendations are provided for the design and implementation of IAIs, as outlined below.

Conclusions for IASs:

1. Authors suggest that a more complete set of agents would result in significantly increased crew performance. The authors felt that the actual number of agents incorporated in the experiment was limited, and the quality of the implementation was fair-to-good though not at the quality of a production system. This suggestion should be taken in light of other research on adaptive aiding.
2. Results suggest that Hierarchical Goal Analysis (HGA) was an effective means of analysis for supporting in route planning, route following, and inter-crew communication.
3. Results suggest that operators of intelligent adaptive interfaces should be given a training period before actually using the system, particularly in life-critical, mission-critical systems.
4. A hybrid IAI based on experience with the adaptive system may increase the operator's understanding of the system and its impact, a phase dependent mix between fully automatic and operator-controlled adaptation.
5. The system should inform the operator of interface changes. For instance, the IAI should either indicate for a few seconds where it is going, or indicate what has changed.
6. The interface should allow the operator to return to the system state that was in effect before the IAI reconfigured the display to increase the sense of operator control.
7. The design of each intelligent agent in a rapid prototype operator interface should be based on reality.
8. Intelligent agents should be made aware of the world state by accessing data fusion interim variables and associated probabilities. The authors suggest that this would allow the IAI to produce strategies that "play the odds".
9. All IAI functions which are studied during design and development, and which are incorporated into an operator evaluation, should be thoroughly researched to confirm that the concept implemented is adequate for the assessment.

Reference:

Edwards, J.L. (2004). Generic Agent- Based Framework For UAV/UCAV - Final Report -A Technical Report prepared by DRDC Toronto (Report No. AIMDC (AC261, February, 2004)).

Overview:

A generic framework for the design and implementation of IA agent-based systems is proposed. The framework was constructed from the elements of the following design approaches: CommonKADS, MAS-CommonKADS, IDEF Standards, Explicit Models Design, Perceptual Control Theory and Ecological Interface Design. Edwards then presents an overview of the procedure for designing and implementing a knowledge based system within the generic framework.

Framework Process:

The following steps were used to generate the proposed framework.

1. As a first step, *CommonKADS* was used to provide a set of guidelines for developing knowledge-based systems. Six models and their elements are identified in this process:

- Organizational Model (organizational or business processes);
- Task Model (high-level tasks and goals of agents in the system);
- Agent Model (who does what);
- Knowledge Model (detailed knowledge required to perform the tasks that the system will be performing);
- Communication Model (communication that must occur among agents (human-agent; agent-human) in the knowledge system); and
- Design Model (examines hardware and software issues related to the construction of the knowledge system. The aim is to take the implementation-independent specifications from the Knowledge and Communication Models and develop a detailed design for constructing the software application, and in the process, preserve the structure of those models.)

2. Next, *IDEF standards* (IDEF3 and IDEF5) were used to complement CommonKADS in two ways. IDEF3 can be used to model the processes and associated agents in real-time. IDEF5 is used to develop ontologies (i.e., expert knowledge elicitation). For example, the knowledge elicited with CommonKADS can be used to develop graphical and textual representation of language. CommonKADS meanwhile can use to turn this modeling of knowledge into the design of software modules and platform requirements.

Explicit Models Design (EMD) was then used to turn the knowledge derived from CommonKADS and IDEF into actual software modules.

1. Task Model. Knowledge about tasks being performed (based on PCT-based hierarchical goal analysis);
2. User Model. Comprised of knowledge relating to the operator’s abilities, needs and preferences (more like customization/personalization);
3. System Model. System’s knowledge about itself and its abilities (goal hierarchy for each agent, and automation level is based on PACT from COGPIT);
4. Dialogue Model. Knowledge related to communication among human and software agents
5. World Model. Representing knowledge of the world relevant to the purpose of the software (i.e., aircraft parameters, GIS, human behaviour, mission scenario and rules of engagement).

Plan recognition (awareness of what the operator is trying to accomplish) and *plan generation* (strategies for the system to help the operator accomplish its goals) are used to determine when the system should initiate automation of tasks. Both plan generation and recognition and feedback concepts are used to support the integration of PCT and EMD components into the generic framework.

*3. Perceptual Control Theory (PCT) and EMD.*PCT and EMD are used to turn the knowledge frameworks developed by IDEF and CommonKADS into design techniques for how the system will function. For instance, how are the goals an operator is trying to achieve determined, what are the plans for achieving those goals, and how it can it assist the operator most effectively?

Goal-driven control loop. PCT is used as a framework to combine all the modules and determine when and how the system should provide assistance (automation of tasks and rule-based adaptation). There are two main concepts in PCT.

1. HGA of Tasks is used in this process.
2. Machine-Learning techniques: the system modifies its adaptation rules (reorganizes the control loops) depending on operator behaviour with the system (randomness).

Automation of Tasks. PCT is used to develop control loop hierarchies and associated goals and sub goals. Together, they can identify when the system should provide assistance, what kind of assistance should be given, and whether or not it should be initiated automatically or by operator control. Plan recognition is used here (error recognition or deviation from plan).

4. *Software Agent Paradigm.* Edwards takes a software agent-based approach to implementing the framework. That is, how the system provides dynamic assistance is completely driven by algorithms. Edwards identifies several advantages of using an agent-based approach. “That “intelligent autonomous agents are ideally suited to taking over some tasks for human operators, serving to support the goals of reduced manning and enhanced performance in a complex environment. Also, the redundancy and distribution across systems leads to improved reliability and safety because, in the event of communication breakdown, mechanisms are in place to compensate”.

Edwards then details how CommonKADS, IDEF standards, EMD, PCT and PACT can be used to develop what agents are needed and how they should be structured.

5. *Ecological Interface Design (EID) is* used to help with the development of the Interface, and only with the interface.

Proposed DRDC Generic Framework

The proposed generic framework that was constructed from the elements of the following design approaches is outlined below:

1. Construct the **Organisation Model** to describe the command and control structure within which the project will be developed;
2. Construct the **Task Model (CK),** including task hierarchies for all agents identified above (use **IDEF3** to represent the hierarchies);
3. Construct the **Agent Model** identifying all operator and system agents and their relationships;
4. Adapt the **Task Model (CK)** to a five level Abstraction Hierarchy according to the levels specified by the **EID approach**;
5. Generate the **Task Model (EMD)** by extending the Task Model (CK) to produce task hierarchies for all agents using **PCT-based hierarchical goal analysis**;
6. Develop the **User Model** according to the need of tracking operator preferences and knowledge
7. Specify the content of the **System Model** to enable representation and use of system preferences and knowledge;
8. Design the **World Model** to contain required information about the environment necessary for the knowledge system to operate effectively;
9. Specify the **Dialogue Model, Communication Model and Co-ordination Model** to govern the format and content of communication among agents (ensure that the ability exists for agents to provide feedback to one another);
10. Use **IDEF5** to design an ontology to represent the contents of all Explicit Models;
11. Develop the **Knowledge Model** to encapsulate the ontology and an associated knowledge base containing information from all Explicit Models;
12. Within the **Knowledge Model, represent the Task Model (EMD) as a hierarchy of PCT loops** that use plan recognition and plan generation to form input perceptions and output behaviours
13. Create **the Design Model** to produce design specifications for the target knowledge-based system; and

14. Apply **EID techniques** to develop specifications for the OMI to the knowledge system.

Conclusions for IASs:

1. Since CommonKADS was developed specifically for guiding the analysis, design and implementation of knowledge-based systems, it is very well suited to producing such a knowledge-based system for UAV/UCAV control.
2. IDEF3 is recommended for temporal and process modelling in the UAV/UCAV generic framework. The CommonKADS approach uses UML for the schematic representation of processes and associated data, agents, tasks and inferences. The author identifies that one of the drawbacks of UML is that it is inflexible in representing temporal relationships and constraints among elements. Unlike UML, IDEF3 permits flexible modelling of temporal concepts. The integration of CommonKADS and IDEF techniques leads to a robust framework for developing knowledge-based systems.
3. IDEF5 is a proven useful tool to design an ontology.
4. PCT and EMD are useful for determining the goals an operator is trying to achieve, the plans for achieving those goals and how a system can assist the operator most effectively.
5. Stability and information flow analyses attained from Hierarchical Goal Analysis using principles from PCT, could contribute to the generation of a robust goal hierarchy for the UAV/UCAV control system.
6. Agents offer numerous advantages for the generic framework. Intelligent, autonomous agents are ideally suited to taking over some tasks for human operators, serving to support the goals of reduced manning and enhanced performance in a complex environment.
7. Ecological Interface Design can play a role in the construction of an adaptive interface for UAV/UCAV control by developing specifications for the operator interface to the knowledge system.

Reference:

Hou, M. (2003). Framework for Optimizing Operator-Agent Interaction. A preliminary Technical Report prepared by DRDC Toronto.

Overview:

This document proposes a generic framework for optimizing operator-agent interaction based on a multiple-agents architecture. This research was performed in the context of controlling multiple UAVs in a complex and dynamic environment.

The author defines an Interaction Model as a need to reflect the work environment and its *dynamic nature*, as perceived by the operator given the current system state and current system goals".

The proposed IAI framework is composed of three Senior Agents:

- *Managing Agent:* This agent manages the information flow, and the control of the display. The agent decides the automation level, and coordinates with the external world, modeling agent, and interaction agents based on the states (knowledge) of all agents (external and internal), and the system itself (including error monitoring and emergency control). The management agent has its working level agent, the modeling agent.

- *External Sensing Agent:* This agent gathers information from external tasks, sensors, datalink and keeps the managing agent and modelling agent updated on the current "world state".
- *Interaction Agent:* This agent handles the information from the interaction with operator and communicates with the managing agent to control the display, automation levels for different agents, 3D audio and speech synthesis, and the emergency system (with feedback). It includes three working level agents: behaviour agent, perception agent, and embedded cognition agent.

The interaction agent's working level agents are:

1. <u>Behaviour Agent (uses an implicit user model):</u> This agent focuses on two kinds of data inputs: keyboard and mouse or other input devices. The data would provide information to the cognition agent and communicates with the interaction agent about the cognitive state of the operator through the process of model tracing.
2. <u>Perception Agent (uses an implicit user model):</u> This agent focuses on low arm movements, facial data processing, eye-gaze tracking, and gestural information. The authors advocate that the operator's attention, fatigue, frustration, and even fear or excitement can be interpreted and transferred to the cognition agent for further analysis.
3. <u>Cognition Agent (integrates the two behavioural user models)</u>: This agent focuses on the analysis of operator workload, situation awareness, complacency and skill degradation (performance) based on the comparison of embedded operator models with the information gathered from the behaviour agent and perception agent.

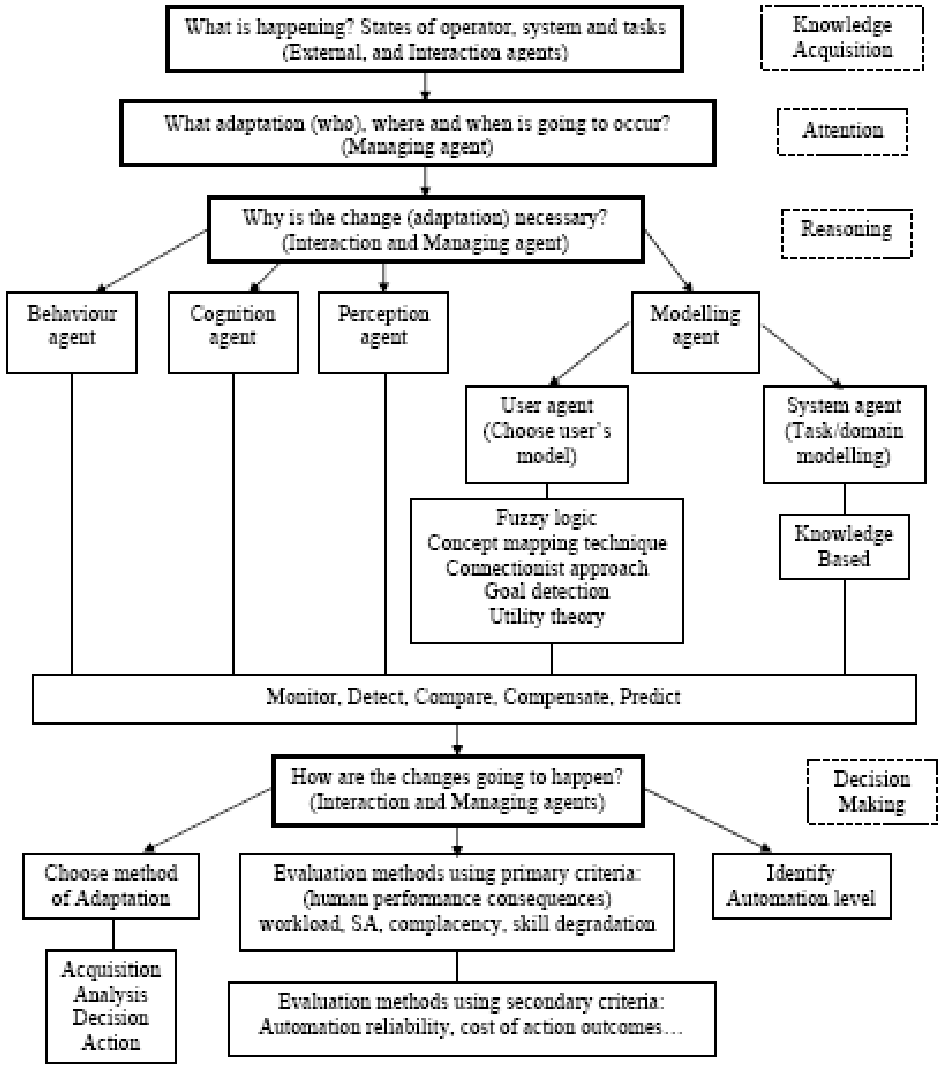

Figure 6. Adaptation and Automation Framework

<u>Conclusions for IASs:</u>

1. The author recommends that an intelligent adaptive interface should incorporate a multi-agent system with the following models: domain, operator task, system, dialogue and interaction.
2. The interface should have knowledge of the operator, system, environment, and the process of various tasks. This can be done with the help of an agent.
3. IAI should be capable of:
   a. Adjusting the forms of information transfer;
   b. Transforming the information contents;

c. Altering/merging modes of information flow; and,

d. Exchanging /combing communication dialogue.

4. Function allocation should be applied in terms of answering the W5 (i.e., what, who, where, why, when, and how) question.

   a. The authors proposed that that function allocation/adaptation should include four major processes: knowledge acquisition, attention, reasoning, and decision making.

3.5 Summary

This section summarises the conceptual frameworks for designing intelligent adaptive systems. This section will also highlight important similarities and differences, and advantages and disadvantages, between the conceptual approaches.

3.5.1 Generic Conceptual Architecture for Intelligent Adaptive Systems

Figure 6 describes the development of a generic conceptual architecture which encompasses all of the approaches reviewed in Sections 8.2 through 8.4. The following four components are common to all IASs:

- *Situation Assessment and Support System.* Comprises functionality relating to real-time mission analysis, automation and decision support. The system monitors and tracks the current mission/goal state, aircraft/vehicle/system status (e.g., heading, altitude, threats etc.), using extensive *a priori* task, goal, tactical, operational, and situational knowledge. Overall, this system provides information about the objective (i.e., *external*) state of the aircraft/vehicle/system within the context of a specific mission, and uses a knowledge-based system to provide aiding (e.g., automate tasks) and support to the operator.

- *Operator State Assessment*. Comprises functionality relating to real-time analysis of the psychological, physiological and/or behavioural state of the operator. Primary functions of this system can include continuous monitoring of workload, inferences about current attentional focus, ongoing cognition (e.g., visual and verbal processing load) and intentions, using extensive *a priori* operator knowledge (e.g., models of human cognition, control abilities and communication).The system also monitors the operator for dangerously high and low levels of arousal. Overall, this system provides information about the objective and subjective (i.e., *internal)* state of the operator within the context of a specific mission. This information is used to optimise operator performance and safety, and provides a basis for the implementation of pilot aiding and support.

- *Adaptation Engine.* Utilises the higher-order outputs from Operator State Assessment and Situation Assessment systems, as well as other relevant aircraft/vehicle/system data sources, to maximize the goodness of fit between aircraft/vehicle/system state, operator state, and the tactical assessments provided by the Situation Assessment system. These integrative functions require that the Adaptation Engine is able to influence the prioritisation and allocation of tasks (i.e., intelligent adaptive automation) and/or determine the means by which information is presented to the operator (i.e., intelligent adaptive interface).

- *Operator Machine Interface*. The means by which the operator interacts with the aircraft/vehicle/system in order to satisfy mission tasks and goals. The Operator Machine Interface is also the means in which, if applicable, the operator interacts with the IAS (e.g., a tasking interface manager). The design of the OMI, as well as the automation, is defined by existing HF and HCI best-practice and standards.

All four components operate within the context of a *closed-loop* system insofar as there is a feedback loop that re-samples operator state and situation assessment following the adaptation of the OMI and/or automation. Similar to Perceptual Control Theory (Powers, 1973; Hendy et al., 2001), the goal is to adjust the level of adaptation so that optimal operator states (e.g., performance, workload etc) are attained and maintained. The criteria for adaptation (e.g., critical events, operator state and behaviour) are described in the next section.

3.5.1.1 Criteria for Implicit Adaptation

In Section 6.4.3.1, two main modes of control over function allocation were described: *explicit* allocation, which refers to situations where the operator has the control over the allocation of tasks; and *implicit* allocation, which refers to the machine allocation of tasks automatically. All implicit adaptive systems require a mechanism by which changes in the OMI and/or levels of automation are implemented or *triggered*. The frameworks reviewed in this section utilise implicit adaptation in one of four triggering conditions:

- *Critical Events.* Critical events are related to mission goals; if critical events do not occur, automation is not invoked. Critical event logic represents the least technically-difficult scheme to implement. For example, if a specific pre-defined critical-event occurs (e.g., a sudden appearance of a hostile aircraft), the appropriate defensive measures are performed by an automated system. One problem is that it is often difficult, particularly in a complex multi-task environment, to adequately specify *a priori* all eventualities that may occur in real settings. Another related problem may arise from its potential insensitivity to the current needs of the operator, as it assumes *a priori* that the occurrence of a critical event necessitates automation of some functions because the operator cannot efficiently carry out these functions and deal effectively with the critical event;

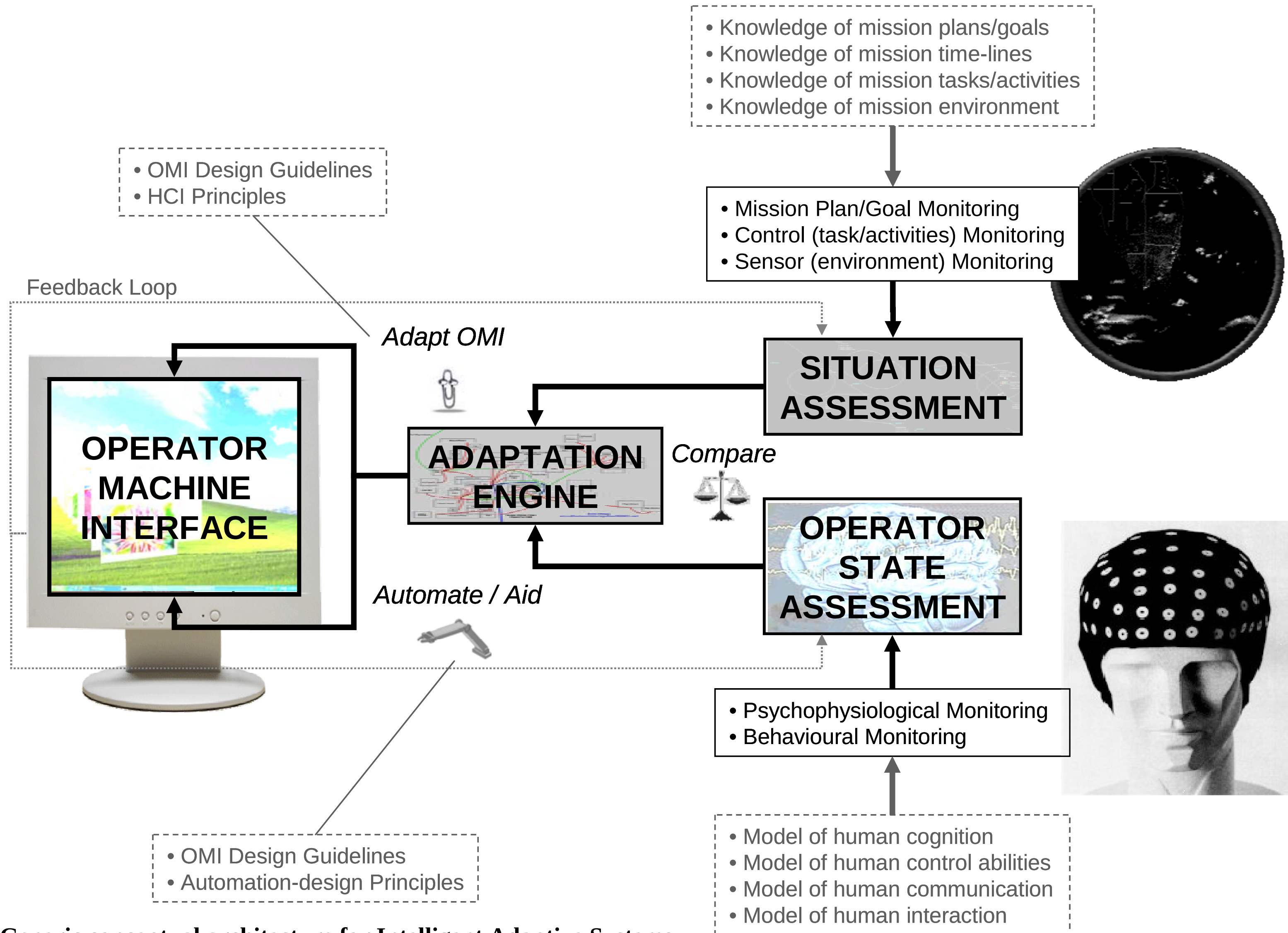

Figure 6: Generic conceptual architecture for Intelligent Adaptive Systems.

- *Operator State and Behaviour*. A dynamic assessment of operator state (e.g., workload) and behaviour is achieved using a combination of psychophysiological or behavioural measures. Changes in the OMI or automation are predicated upon the momentary assessment of operator state or behaviour where the violation of one or more pre-determined criteria triggers the adaptation. The main advantage of this approach is that the measurement is real-time and reasonably sensitive to unpredictable changes in operator cognitive states. However, this approach is only as accurate as the sensitivity and diagnosticity of the measurement technology. Further, due to the latency inherent in these kinds of 'closed-loop systems' (i.e., feedback), state and behavioural measurement usually occur 'after the fact'; that is, it follows the point in time when an adaptive change may have been required due to changes in task demands or operator behaviour. Finally, in highly automated systems in which the operator is not required to make many overt responses, behavioural measurement may be so impoverished as to be regarded impractical;

- *Operator Modelling*. Operator modelling can be used in conjunction with operator state and behaviour modelling, whereby the adaptation strategy is enhanced by knowledge of human cognition and action. The system utilises model(s) of human cognition to predict (i.e., feed-forward) the human's performance on a task, and to take control when the human is not able to cope with task demands. Modelling techniques have the advantage that they can be implemented off-line and be incorporated into on-line operator state and behaviour adaptation systems. However, this approach is only as good as the theory behind the model, and many models may be required to deal with all aspects of operator performance in a complex task environment. Many approaches to adaptation invoke automation or OMI adaptation on the basis of impending performance degradation, as predicted by a human performance model. Models can be classified broadly as either optimal performance models (i.e., signal detection, information and control theories), or information processing models (i.e., such as multiple resource theory). For example, an adaptation strategy based on the multiple resource theory (see Wickens, 1984) would predict performance degradation whenever concurrent tasks placed excessive demands on finite common cognitive resources. When the combination of information from these different sources exceeds some threshold in the algorithm, tasks are allocated to the system or the OMI is adapted in such a way as to reduce task demands. Adaptation based on cognitive models is dependent on predictive validity. However, no quantitative model of multiple resource allocation exists; they are descriptive models. Another difficulty associated with operator modelling is that it requires an on-line assessment of what the operator intends to do (i.e., goal-tracking). This assessment is especially problematic in multi-task situations; the activities and intentions of operators involved in a single-task would be obvious; and,

- *Hybrid*. These systems combine performance and modelling, or critical-event and performance, or other possible combinations of these methods, in order to optimise their relative benefits (Hilburn et al., 1993). Hilburn et al. propose that a hybrid system incorporating more than one of these methods might optimise their relative effectiveness (i.e., optimise the benefits and minimise the drawbacks). Figure 7 describes a hybrid implicit adaptation system in which the system compares operator behaviour with beliefs about the operator's intent, which then drives decision aiding and interface adaptation. The system model of the operator's interaction with the system is based on a combination of knowledge of critical events and models of human cognition. A probability distribution about the operator’s goals and intent (bar graph) is computed from this knowledge and observations of the operator. Actions, such as task automation or interface adaptation, are then generated based on their expected utility.

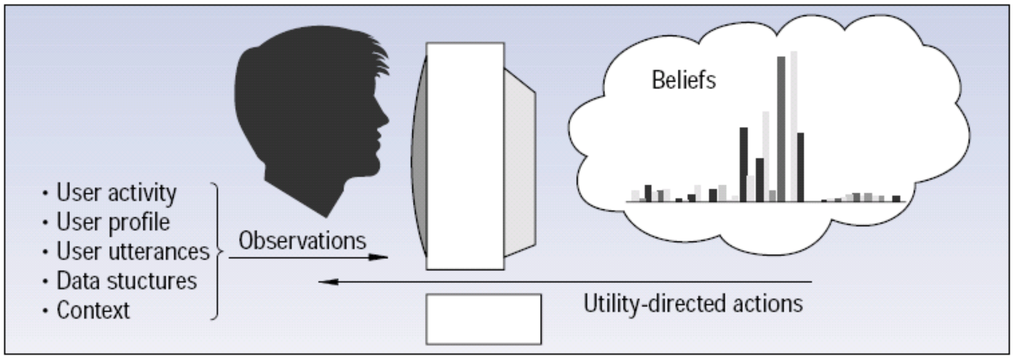

Figure 7: Hybrid implicit adaptation system (Horwitz, 1999, p. 18).

3.5.2 Comparison of Conceptual Frameworks

Table 6, Table 7, and Table 8 summarise the advantages and disadvantages of the frameworks, the relationship between the frameworks in terms of authority, agency and user model, and which frameworks are applicable to a given situation (i.e., domain applicability).

Table 9 provides a summary of IAH, IAI, and IAA frameworks.

Table 6: Summary of Intelligent Adaptive Interface Frameworks.

	Adaptive Icon Toolbar	ConCall	SAWA (USA)	Work-Centered Decision Support
Advantages	Adaptation of the OMI can increase efficiency of customization and learning of interface features. Features, functions, and content can be provided at the right time. Useless features can be removed. Compensate for individual characteristics. Provide context dependent help.	Content can be provided at the right time. Compensate for individual characteristics.	An offline system for decision making; therefore no real-time, criticality issues. Semantic Web technologies can be used for representing and reasoning about knowledge pertinent to a situation's domain. Content can be provided at the right time. Compensate for individual/population characteristics. Provide context dependent information. Decrease mental workload.	A work domain ontology was useful as the organizing framework across the decision support tool set. Minimizes perceptual, cognitive, and motor task demands associated with identifying, seeking, or interpreting relevant information and producing work artefacts. Automated agents need to be observable (or transparent/visible) so that operators are able to see what the automated agents are doing and understand what they will do next relative to the state of the task. Ecological Interface Design is an effective means of providing work-centered decision support. *Cognitive work analysis (CWA)* as part of the human-centered design process is an effective means of establishing system requirements to ensure a human-centered system. Provide context dependent information Compensate for individual characteristics.
Disadvantages	Potential for poor user models. Lack of transparency and predictability. Lack of controllability of the system.	Potential for poor user models. Too many recommendations therefore operators stopped using it out of frustration. Due to a lack of a proper mental model of the system, operators' were found to request a function that would undo a previous adaptive change that the system has determined would be right for the	Semantic Web Technologies are difficult to implement.	How much "visibility" needed is questionable (i.e., not at all but then issue of trust and mistrust can occur or fully visible such as the Microsoft "PaperClip" which takes advantage of assistant and subordinate metaphors). Potential for poor task models.

	Adaptive Icon Toolbar	ConCall	SAWA (USA)	Work-Centered Decision Support
		operator. Lack of controllability of the system. Operators also wanted an UNDO function and wanted to be less disturbed.		
Authority	The operator has authority over analysis and implementation of adaptation while the system has authority over acquiring the information. A shared role for implementing adaptation.	The operator has authority over analysis and implementation of adaptation while the system has authority over acquiring the information. A shared role for implementing adaptation.	Operator always in control of responding while the system automatically analyzes and synthesizes information and provides recommendations.	Operator control over implementation of recommendations.
Agent	The system performs all roles.	The system performs all roles.	System analyses and synthesizes information and makes decision recommendations but operator implements decision making.	System acquires and analyzes information and makes recommendations.
User Model	Operator behaviour.	Explicit user model.	Monitors evolving situation but not operator characteristics.	Based on task model.
Domain Applicability	Web and stand-alone applications, features, functions, and content can be provided at the right time.	Web and stand-alone applications, features, functions, and content can be provided at the right time.	Aviation. Decision aiding/information management.	Decision making, information management.

	Stock Trader	Personal Web Searcher	DIAManD
Advantages	An implicit user model is an effective and non-obstructive means of constructing a user model. Adaptation of the OMI can increase efficiency of customization and learning of interface features and of stock trading. That is, as the operator began to better understand how the system works, they began to accept more recommendations.	Mixed-initiative interfaces (e.g., direct interaction with an agent) can increase situational awareness and develop better mental model of the system. Content can be provided at the right time. Useless features can be removed. Compensate for individual	A mixed-initiative framework (e.g., DIAManD) in which the learner and human operator are each participants in a dialogue could improve the learner's hypothesis with minimal effort on the part of the operator. Adaptation of the OMI can increase efficiency of customization and learning of

	Stock Trader	Personal Web Searcher	DIAManD
	Compensate for individual characteristics. Provide context dependent information.	characteristics. Provide context dependent information.	interface features. Compensate for individual characteristics. Provide context dependent information.
Disadvantages	Burden the operator with an increased workload by having to either decide or implement the adaptation. Potential for human OOTL performance problems.	Potential for poor user models. Potential for human OOTL performance problems.	Burden the operator with an increased workload by having to either decide or implement the adaptation. Obtrusive. Difficult to maintain the operator "in-the-loop".
Authority	Operator control over implementation of recommendations.	Operator control.	Operator.
Agent	System acquires and analyzes information and makes recommendations.	System analyzes and makes recommendations.	System.
User Model	Based on operator behaviour.	Based on operator behaviour.	Monitors evolving situation. Based on operator behaviour and task model.
Domain Applicability	Search engine, information management, decision aiding.	Search engine, information management, decision aiding.	Decision making, information management.

Table 7: Summary of Intelligent Adaptive Automation Frameworks.

	CAMA (Germany)	Co-Pilote Electronique (France)	Playbook
Advantages	Mainly for enhancing situational awareness. Content can be provided at the right time. Compensate for individual characteristics. Provide context dependent help. Decrease mental and physical workload.		Tasked systems are always sub-ordinate, but know enough about the tasks in the domain that instructing them is vastly easier than instructing traditional automated systems. Enabling a system to behave more like an intelligent subordinate, operators may be more tolerant of their weaknesses and acceptable of their capabilities in a controlled setting (operator acceptance). Playbook provides a complete architecture for the integration of human input, intelligent *a priori* planning, reactive planning and event handling, and ongoing automation control loops. Affords collaboration between interfaces and operators in order to achieve the operator's goals.
Disadvantages	Still has many modules (16) and therefore complex to implement. Potential for human OOTL performance problems.	Potential for human OOTL performance problems.	Tasking interfaces should not rely on a predefined set of task models. The operator should be able to create novel tasks and to store components of models which are useful. Operators need sufficient training for interacting with the tasking interface.
Authority	Sharing of initiation but human has ultimate control.	Operator always in control of implementation.	Operator always in control.
Agent	Mostly the system except for responding.	System performs the analysis and decision recommendations while the operator implements decisions.	Sharing of roles between system and human.
User model	Functions for situation assessment and mission planning make up the core of tactical mission management systems.		Based on a shared task model.
Domain Applicability	Aviation.	Aviation.	Decision aiding/information management.

	CAMA (Germany)	Co-Pilote Electronique (France)	Playbook
(i.e. what, when & how)	Maintain situational awareness. Decision aiding/information management.	Decision aiding/information management.	Delegation of tasks.

	Intelligent Classroom	LookOut
Advantages	Human-machine cooperation can be achieved by allowing an operator, in executing her part of a plan, to expect a system to help in executing part of the plan. A plan is a set of processes (often to be executed by a number of different agents) that when run together successfully, accomplish some goal. Plans attempt to express a common understanding of how a speaker and an audio/ visual assistant interact. The more the system understands its operators and their tasks, the more useful it will be for them. This requires a learning module. The same techniques implemented in the Intelligent Classroom can be applied to a broad range of interactive applications. Adaptive automation performed in real-time.	Adaptive automation performed in real-time. The system is designed to continue to learn from operators through caching operator behaviour with the system and by the operator specifying a policy for continual learning (e.g., set system to cache behaviour at particular times. The decision of automation initiation is based on when an agent believes that they will have greater expected value than inaction for the operator, taking into consideration the costs, benefits and uncertainties in the operator's goals.
Disadvantages	Potential for poor user models. Obtrusive. May be difficult to maintain the operator "in-the-loop, and may lead to OOTL performance problems. Potential to increase workload (operator may have to decide to implement and/or automation implementation is inappropriately applied). Operator may feel out of control.	Potential for poor user models. Potential to increase workload (operator may have to decide to implement and/or automation implementation is inappropriately applied). May be difficult to maintain the operator "in-the-loop, and may lead to OOTL performance problems. Obtrusive Operator may feel out of control.
Authority	System/Human share tasks dynamically.	The system performs all tasks but the operator has control over acquiring operator specified information and shares the role of taking action

	Intelligent Classroom	LookOut
		to system recommendations.
Agent	System.	System.
User model	Monitors evolving situation. Based on operator behaviour and task model.	Inferred probability of a user goal (hierarchical goal model).
Domain Applicability (i.e. what, when & how)	Assistant aiding for execution of tasks (non-delegated). Increase efficiency of task (e.g., time saving).	Assistant aiding for execution of tasks (non-delegated). Increase efficiency of task (e.g., time saving).

Table 8: Summary of Intelligent Adaptive Hybrid Frameworks.

	Cognitive Cockpit (UK)	PA/RPA (USA)	CASSY (German)	DRDC IAI Framework (Canada)
Advantages	Feedback/Feed-forward architecture allows system adaptiveness (dynamic function allocation). Functional analysis of cognitive work provides essential foundations for the successful development and implementation of cognitive cockpit technologies for pilot aiding. Showed that interfaces, tasks, and automation can be managed by a tasking interface system based on a shared task model. Affords collaboration between systems and operators in order to achieve the operator's goals.	More emphasis on development of OMI. Benefits of an explicit, integrative framework (task model). Having a task-based framework proved to be an effective means of coordinating and minimizing the costs of revising or extending multiple, diverse sets of subsystems. The use of Intelligent Object-Oriented Design (IOOD) provides a series of steps to transform requirements to more abstract views of objects. Iterative development is most productive when supported by a set of management, design and testing tools (e.g., Plan Goal Graph Tool (PGG); Display Analyst). Affords collaboration between systems and operators in order to achieve the operator's goals.	Less complex framework. Less resources needed (e.g., no psycho-physiological measures). Reduced human OOTL performance problems. Algorithms based on a-priori probabilities for possible hypotheses have proven useful for recognizing and estimating operator intent.	UAV Simulation Tests found that : • Operators at all crew positions performed more effectively from both quantitative and qualitative perspectives when the IAI multi-agent system was selected ON. • When IAI was ON, CTSs were shortened, less tasks were shed, the UAV trajectory scores were better and much less time was spent in the no-fly areas. • Operators' overall SA was improved and overall workload was reduced as well. Affords collaboration between systems and operators in order to achieve the operator's goals. CommonKADS, IDEF standards, EMD, PCT and PACT are useful for developing agents. Agents offer numerous advantages (e.g., automation).
Disadvantages	Highly complex and difficult to implement. Analysis is in-depth, time-consuming and requires trained HF professionals. Limited resources due to complexity (although this is changing with time). Lack of transparency and	Highly complex and difficult to implement. Analysis is in-depth, time-consuming and requires trained HF professionals. Limited resources due to complexity (although this is changing with time). Lack of transparency and predictability.	Still very complex that requires a lot of analysis.	UAV simulation tests found that: • The crews came in for only two days and the novelty of the conventional interface would not have worn off. • The crewmembers would rather work with the interface manually than give up control to the IAI. • The conventional interface

	Cognitive Cockpit (UK)	PA/RPA (USA)	CASSY (German)	DRDC IAI Framework (Canada)
	predictability.			was designed to be effective, however the IAI ON interface still performed better. • Participants had been trained on the conventional interface for which they had developed work strategies and not on the IAI. With the IAI functionality selected ON, the participants may rely on the original work strategies because they were known and effective. Highly complex and difficult to implement. Analysis is in-depth, time-consuming and requires trained HF professionals.
Authority	More emphasis on automation of tasks based on feedback and feed-forward architecture. Operator always in control except in critical conditions (e.g., autopilot turns on when pilot looses consciousness).	More system autonomy for analysis and recommendations for decisions but operator always in control, especially for implementation of automation.	Operator always in control of implementation.	Human always in control except when analyzing and synthesizing the information. Goal-driven control loop for the initiation of automation.
Agent	Full sharing of tasks between system and operator.	More emphasis on supporting the pilot with his task (shared knowledge to plan and suggest courses of action and to adapt cockpit information displays and the behavior of aircraft automation).	System performs most of the tasks under the control of the human except for responding.	Sharing of tasks between human and system except for analysis.
User model	More emphasis on operator state (workload). Tracks goals/tasks implicitly and	Less emphasis on operator state. CIM Intent estimation is used to assess if system action is required (to assess pilot	Operator behaviour (crew actions are derived indirectly by interpreting aircraft data for pilot	Task/function model but no monitoring of operator behaviour or state.

	Cognitive Cockpit (UK)	PA/RPA (USA)	CASSY (German)	DRDC IAI Framework (Canada)
	updates as necessary. Intent estimation is used to assess if system action is required.	intent).	intent and error recognition.	Interaction agents (behaviour, perception and cognition) (Hou, 2003). Plan recognition and generation are used in conjunction with pre-defined goals/tasks and matched to a World state to assess if system action is required.
Similarities	Similar frameworks based on several modules: task/function-based, environmental, mission and operator characteristics by monitoring, assessing and implementing adaptive interface and/or automation. Potential for poor user models (Does not matter what the model is based on. I.e., psycho-physiological measures or plan generation and recognition/intent estimation). Lack of controllability of the system. Burden the operator with an increased workload by having to either decide or implement the adaptation. Obtrusive.			
Domain Applicability	Aviation, UAV. Increase task efficiency. Decision aiding/information management. Managing increasing complex systems. Sharing of tasks/functions.			

Table 9: Summary of Intelligent Adaptive Interface, Automation and Hybrid frameworks.

Intelligent Adaptive Hybrid	• Domain Areas: Aviation, UAV, decision aiding/information management. • Adaptive automation (of tasks) more prevalent. • Comprehensive. • Critical (more serious consequences of errors). • Real-time adaptation. • Operators are more likely to have authority over implementation of automation, or adaptation of OMI. • User model: usually very complex (includes many factors); usually elicited implicitly (physiologically-based on workload principles).
Intelligent Adaptive Interface	• Domain areas: adaptive and adaptable UI, applications (e.g., web and standalone), search engines, information management. • Involves a more narrow scope (only perform some of the roles, not always all of them) • Non-critical applications. • Learning IAI (algorithms) is more prevalent (suspect it is easier to implement because systems are less complex, and not real-time). • User model: less complex if elicited implicitly then more often behaviour-based.
Intelligent Adaptive Automation	• Adaptive automation performed in real-time. • Non-critical applications. • Operators have authority over implementation of automation. • Provide context dependent help.

4 Analytical Techniques

4.1 Introduction

Analytical approaches such as Mission Function Task Analysis (MFTA), Cognitive Work Analysis (CWA) and Applied Cognitive Work Analysis (ACWA) can provide the OMI communication, visual display and control requirements needed for the design of intelligent adaptive systems as well as a functional decomposition of the tasks within the domain envisaged for it. In addition, they provide the means to capture more detailed knowledge from Subject Matter Experts for embedding in an intelligent knowledge based system. In order to intelligently adapt the interface to an operator’s needs, the system must be privy to the current mission status, platform status (e.g., heading, altitude and threat) and also be invested with extensive a priori tactical, operational and situational knowledge. This provides information about the objective state of the platform within a mission/goal context and provides a basis for the adaptation of the interface to support the operator.

To achieve its goals, the design of an IAS requires a validated requirements gathering and analysis methodology to provide a comprehensive view and understanding of the tasks and cognitive processes involved in the complex environment that will include an intelligent adaptive systems. The following review will provide a template and the basis for an understanding of other published methods in order to recommend the methodology or methodologies that will best support the capture and analysis of processes, tasks and requirements for future IAS design activities.

4.2 Analysis Methodology

The section reviews the following analysis methodologies:

- Hierarchical Task Analysis (HTA);
- Mission, Function and Task Analysis;
- Hierarchical Goal Analysis based on the Perceptual Control Theory;
- Goal-Directed Task Analysis (GDTA);
- Cognitive Task Analysis (CTA);
- Team Cognitive Task Analysis (Team CTA);
- Applied Cognitive Task Analysis (ACTA);
- Cognitive Work Analysis; and,
- Applied Cognitive Task Analysis.

4.2.1 Hierarchical Task Analysis

Hierarchical Task Analysis [3]

Reference:

Crystal, A. & Ellington, B. (2004). *Task Analysis and Human Computer Interaction: approaches, techniques, and levels of analysis.* Proceedings of the Tenth Americas Conference on Information Systems, New York, New York.

Hone, G. & Stanton, N. (n.d.). *HTA: The Development and Use of Tools for Hierarchical Task Analysis in the Armed Forces and Elsewhere*. Accessed at http://www.hfidtc.com/pdf/reports/HTA%20report.pdf, January 28, 2007.

Miller, C. & Vicente, K. (2001). *Comparison of Display Requirements Generated via Hierarchical Task and Abstraction-Decomposition Space Analysis Techniques*. International Journal of Cognitive Ergonomics 5(3), 335-355.

Stanton, N. (n.d.). *Hierarchical Task Analysis: Developments, Applications, and Extensions*. Accessed at http://www.hfidtc.com/pdf/reports/HTA%20Literature%20Review.pdf, January 28, 2007.

Overview:

Hierarchical Task Analysis is a broad, simple and informal, and representationally streamlined task analysis method. HTA describes a system in terms of its goals, which are expressed in terms of some objective criteria. HTA is able to describe a system in terms of the tasks conducted by individuals, as well as producing a systems analysis. Thus, HTA is able to describe human and non-human tasks performed by a system.

HTA focuses on what an Operator is required to do, in terms of actions and/or cognitive processes to achieve a system goal. Task knowledge is structured in a hierarchical action means-ends relationship (how subtasks may be composed to accomplish higher level tasks), and sequential relationships (how tasks must be performed temporally) (Miller & Vicente, 2001).

Process:

The method describes a task in terms of a hierarchy of operations and plans, and identifies the conditions under which the sub-tasks should be completed in order to meet the system goals. The methods result in a hierarchy of three levels of task analysis, including:

- Goals. A goal a human wants to achieve;
- Tasks. Structured set of tasks and plans that are outlined in a sequence to achieve the goal; and,
- Operations or Actions. Simple tasks that have no further structure/plan; these are the lowest level of decomposition.

HTA views tasks in a more abstract sense, as a set of interlinked goals, resources, and constraints (Crystal & Ellington, 2004).

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[3] Note that for this reference, and all subsequent references, these icons relate only to the publications cited.

Miller & Vicente (2001) indicate that HTAs are generally presented in two formats:

- Graphical format shows the hierarchical and aggregate relationship between tasks. Each layer of the hierarchy represents a series of tasks/actions which accomplish the higher level task. A plan is always placed along the vertical line connecting the lower level tasks to the higher level tasks to identify how, when, and in what order they must be performed to accomplish the higher level task. The plan outlines the parallel or sequential relationships amongst the tasks; and,
- Tabular format with progressive indenting and task numbering used to track task decomposition. This format may make it more difficult to visualize task relationships; however, it facilitates additional information links to other tasks (e.g., duration or frequency information, potential for human errors, resources required, etc.).

HTA information sources include: operator interviews, direct observation, and training or procedural/operational manuals.

<u>Advantages</u>:

1. Cost efficient task analysis method;
2. Easy to learn and apply;
3. Results can provide the input to a variety of other analyses; and
4. Provides an analytical framework for designers.

<u>Disadvantages</u>:

1. Provides a narrow view of the task, and should normally be used in conjunction with other task analysis methods to increase its effectiveness, and to develop a more complete understanding of human activity.
2. Generally used to describe simple rather than complex tasks.

<u>IAI Applicability</u>:

1. Provides a model for task execution, enabling interface designers to envision the goals, tasks, subtasks, operations, and plans essential to operators' activities (Crystal & Ellington, 2004).
2. Can be easily extended to provide system and information requirements.
3. Information needs (both input and output) are typically deduced for the tasks. These needs, when combined with task relationship information, can provide a basis for prioritizing, clustering, filtering, or sequencing information presentation in an interface design (Miller & Vicente, 2001).

4.2.2 Mission, Function, and Task Analysis

Mission, Function, and Task Analysis

Reference:

Chow, R., Kobierski, B., Coates, C. & Crebolder, J. (2006). *Applied Comparison between Hierarchical Goal Analysis and Mission, Function, and Task Analysis.* Proceedings of the Human Factors and Ergonomics Society 50th Annual Meeting.

Darvill, D., Kumagai, J. & Youngson, G. (2006). Requirements Analysis Methods for Complex Systems. Technical Report to Defence Research & Development Canada Valcartier (CR 2005-076).

Overview:

MFTA is a top-down analysis that is generally used during the initial stages of systems development to specify requirements. This concept promotes a link between analysis and design, and validation and verification are completed at each step of the analysis.

Baseline scenarios are analysed to produce a composite scenario (mission) that identifies all relevant and important functions of the system (Chow et. al., 2006). A mission is decomposed into mission segments, which are then further decomposed into functions, followed by lower-level functions. Decomposition may be completed according to functional groupings (e.g., navigation, communication), or different points along a timeline (e.g., take-off, cruise, landing).

At the lowest level, function allocation is completed to assign a function to either a human or a system. Additional information can also be linked to each task and function, such as:

- Completion time;
- Relevant perceptual and cognitive tasks;
- Skills and knowledge required; and,
- Identification of critical tasks.

Process:

MFTA is generally structured according to the following:

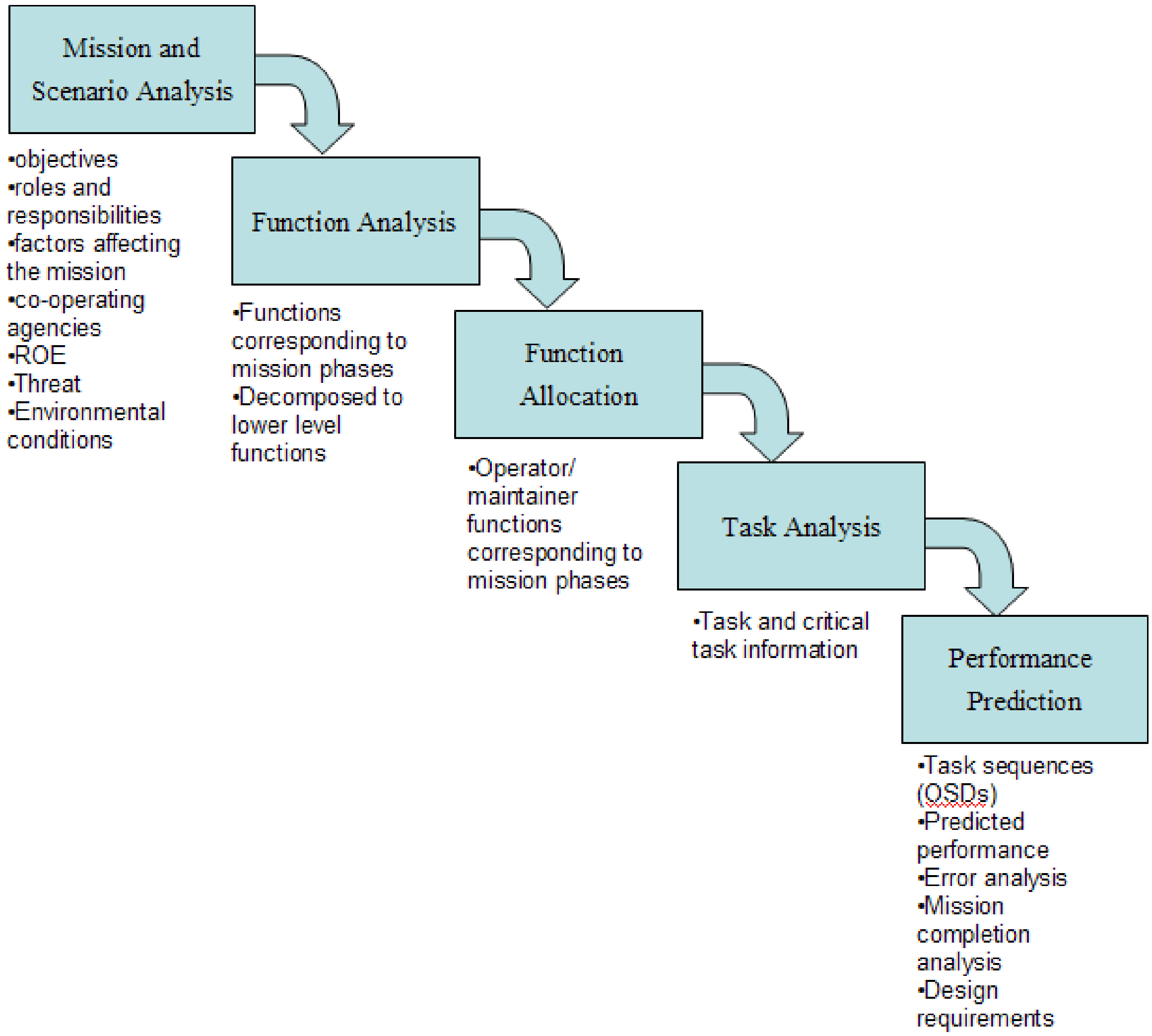
- Mission analysis and scenario development. defines the overall requirements of the system. The system is described in terms of its operational requirement (what the system must do), and the environment or scenario under which the operational requirements must be completed. The mission is described in detail, to identify important mission phases, system functions, activity timeline, and external events which may impact the system;
- Function analysis. the system is analysed in terms of the functions which must be performed. Function analysis is structured according to a top-down hierarchy. Decomposition of functions is graphically represented via Function Flow Diagrams, outlining the operational characteristics of the mission. Function decomposition is completed when the task level is attained;
- Function allocation. Functions are allocated to a system component or to a human. Functional allocation identifies whether the system can adequately support the execution of the mission, and corresponding functions. If deficiencies are identified in the baseline system, alternate

allocations are proposed and assessed. Function allocation analyses provide the basis for subsequent efforts relating to task analysis and description, performance analysis, display and control selection, or crew-station design (Darvill et. al., 2006).

- Task analysis: Defines what an Operator is required to do, and identifies the interaction between the Operator and the system. Task analysis permits the application of relevant knowledge on human performance (Darvill, 2006). A task analysis may characterize each task according to the following elements:
    - Task description;
    - Task completion time;
    - Action requirement;
    - Information requirement; initiating conditions;
    - Feedback;
    - Cognitive processing requirements;
    - Decision requirements;
    - Priority;
    - Criticality;
    - Knowledge;
    - Skills; and
    - Ability.

Performance prediction. predicts how well an Operator will perform a task. The mission, function, and task analysis results are linked to system performance criteria. These criteria confirm the function allocation to Operators or the system.

Darvill et. al., (2006) provides a graphical ‘waterfall’ relationship of MFTA elements, as illustrated below.



Advantages:

1. Relatively easy method for Subject Matter Experts and analysts.
2. Able to use past experience to outline the information flow/activities for a given scenario.
3. Task analyses and data can be reusable between missions/systems.
4. Able to identify increased workload, and task conflicts.

Disadvantages:

1. Extensive effort to complete a MFTA.
2. Individuals conducting the MFTA may not be the same individuals responsible for designing the system, creating the need for a large data transfer.

IAI Applicability:

1. MFTA task hierarchy would need to be modified and expanded to consider intelligent agents

(Chow et. at., 2006).

2. Produces information and action requirements which could inform training and interface design, or task re-allocation to support multiple operators/systems.
3. Able to identify high areas of workload and task conflicts, identifying where system support may be required.

Reference:

Chow, R., Kobierski, B., Coates, C. and Crebolder, J. (2006). Applied comparison between hierarchical goal analysis and mission function task analysis. Proceedings of the 50th Human Factors and Ergonomics Society Conference, San Francisco, CA

Overview:

This paper compares the application of Mission, Function and Task Analysis and Hierarchical Goal Analysis to identify requirements for systems design in a military context. The two approaches were used to analyze three tactical positions in the Operations Room of a Halifax Class naval frigate.

The first application used HGA to support the design of intelligent, adaptive interfaces for UAV control by a 3-person, airborne crew. The second application used HGA to identify critical activities that could benefit from advanced decision aiding technology in the operations room of a Halifax-class naval frigate.

Findings:

MFTA

1. Relatively easy to apply by analysts and subject matter experts, who had little difficulty identifying actions (i.e., tasks) that need to be performed to support a given function or that need to be performed in parallel or in sequence. Most analysts and SMEs were familiar with MFTA.
2. Task sequences were constructed bottom-up from task lists; they supported evaluation of the operators' abilities to multi-task.
3. The volume of effort required is quite extensive (e.g., 2600 tasks to analyze) and could increase rapidly if more operators were added (cost).
4. More difficult to transfer requirements to design recommendations because this analysis produces very detailed data.

HGA

1. Required substantial training, to convert operators from thinking about what actions a given operator needs to perform, to thinking about who needs to assess effects and how effects need to be assessed.
2. Needed to be worked both top down and bottom-up (reflecting how an operator may direct attention), and the endpoint for analysis was not as obvious. SMEs found it harder to review goal hierarchies than task sequences, because goals in the same part of a hierarchy were not necessarily aligned or related in time.
3. Operators were assigned after all goals were identified, so consideration of all operators who might interact with the targeted operators was already “built into” the analysis (cost).
4. Transfer of requirements to design recommendations is more direct as the HGA database is more abstract in nature, but smaller and more focused in that it does not attempt to track a mission timeline. Information to be displayed and controls necessary to complete specific goals

are clearly indicated. Also included are other control requirements (e.g., limit access to a variable) that may be addressed by system or process design, and shared information requirements (e.g., feedback on a goal that affects another goal) that may be addressed by interface design or by facilitating communication between operators.

Conclusions for IASs:

1. MFTA was found to be easy to learn and use whereas HGA required a heavy initial investment in terms of time and effort to learn, and required continual support from a knowledgeable support team to ensure that the domain experts' efforts were meaningfully applied.
2. MFTA seemed especially suited for the design of training or interfaces for specific operators.
3. HGA seemed especially suited for system-level design, such as the design of a new operations room involving new roles, physical layouts, and technological support.
4. The transfer of requirements to design recommendations was more direct and easier for HGA than MFTA.

4.2.3 Hierarchical Goal Analysis based on the Perceptual Control Theory

Hierarchical Goal Analysis based on the Perceptual Control Theory

Reference:

Darvill, D., Kumagai, J. & Youngson, G. (2006). *Requirements Analysis Methods for Complex Systems.* Technical Report to Defence Research & Development Canada Valcartier (CR 2005-076).

Hendy, K., Beevis, D., Lichacz, F. & Edwards, J. (2001). *Analysing the Cognitive System from a Perceptual Control Theory Point of View*. Defence Research and Development Canada (TO) Report: SL2001-143.

Hou, M. & Kobierski, B. (2005). *Performance Modeling of Agent-Aided Operator-Interface Interaction for the Control of Multiple UAVs*. 2005 IEEE International Conference on Systems, Man, and Cybernetics.

Kobierski, B. (2004). *Hierarchical Goal Analysis and Performance Modelling for the Control of Multiple UAVs/UCAVs from an Airborne Platform*. Contract Report to Defence Research and Development Canada (CR 2004-063).

Overview:

The Perceptual Control Theory models human-world relationships and considers the human as a negative feedback loop system, interacting with an environment prone to disturbances. This negative feedback system is error-correcting, and therefore, the human exhibits compensatory behaviours to achieve system stability. Hendy et. al., (2001) describe the PCT model as a multi-layered system, with multiple goals providing the reference points for a hierarchical organization of control loops. These loops can provide control at many levels, including the lowest levels of sensory processing, to higher-level, more abstract goals.

Hendy et. al., (2001) indicated that:

> "In PCT terms, an emitted action or behaviour is in response to the presence of an error, or difference, signal. The emitted action transmitted purposefully, with the intention of changing the state of the world so that the Operator's perception can be made to match a desired state or goal, reducing the error signal". "The hierarchical structure of goals and objectives, from the highest level of abstraction to the lowest, represents the hierarchy of control loops that potentially will be active during the life of the system. Any goal/objective not served by a control loop has no influence over a variable in the external world, and will cause no behaviour/output to be emitted. Alternatively, all system variables that are to be influenced must be associated with a goal or objective".

Hierarchical Goal Analysis combines function and task analysis into a signal process. HGA is rooted in PCT, and therefore is based on the idea that humans and machine can be described in terms of a hierarchical control model (Hou & Kobierski, 2005). Furthermore, HGA emphasizes that goal directed human activity is driven by a process of a closed loop negative feedback control. HGA claims that all human behaviour occurs as a result of a perceptually driven, goal-referenced feedback system. This approach acknowledges the goals and knowledge of humans in the system, but is equally concerned with the sensory, perceptual and psychomotor requirements.

<u>Process:</u>

HGA starts with a goal at its highest level of the hierarchy. Analysing the goal in a top-down framework, the HGA requires a decomposition of the goal from its highest level, down to its lowest levels. From a PCT perspective, goals are divided in perceptual terms.

Hendy et. al., (2001) provides the following rules for conducting a PCT-based HGA:

- All points are generalized goals/objectives until assigned to a human or machine. Therefore, goals assigned to humans are perceptual goals that drive human activity. Any goal that is not assigned to a human or machine is not actively controlling (i.e., this type of goal is likely not to be achieved as it is not assigned to any agent). All PCT goal statements are in the form of "I want to perceive…..".
- All control loops involve a variable that in influenced/controlled by the loop action. Each goal/objective must have an influenced variable. If a human is assigned to a goal/objective, the variable can be internal or external.
- Moving downwards through the hierarchy creates sub-goals/sub-objectives. The decomposition into sub-goals and sub-objectives follows a means-end hierarchy.

PCT-based HGA requires specific cognitive and perceptual information related to each goal loop at each hierarchical level, such as (Darvill et. al., 2006):

- Required Knowledge States. both declarative knowledge and situational knowledge are identified;
- Initiating Conditions. when the task begins;
- Ending Conditions. When the task is considered complete (to move to the next task);
- Perceptual/Cognitive Processes. processes associated with the goal chosen from a list relevant to the current goal;
- Inputs/Sensations. inputs and sensations chosen from a list, such as: for memory – verbal recall required; for visual – text is required);
- Outputs/Behaviours. outputs and behaviours chosen from a list, such as: for voice – establish radio link; and

- Multiple Agents. Multiple agents may be interacting through their influence on shared environmental variables.

The assignment of objectives is a major engineering decision that fundamentally shapes the to-be-designed system (Hendy et. al., 2001), so no assignments to human or machine are made using HGA until the goal-related information has been collected for all system goals within the hierarchy (Darvill et. al., 2006).

Advantages:

1. PCT-based HGA addresses many of the deficiencies associated with traditional HGA (Hendy et. al., 2001).
2. PCT-based HGA provides an additional step to Hierarchical Task Analysis such that it acknowledges the need for error correction at all levels within the hierarchy.
3. HGA can be integrated into the engineering design process.
4. Considers all goals (highest-level to lowest-level) as possibilities to be assigned to agents, either human or machine.

Disadvantages:

1. Considerable time.
2. Training and experience required to implement.

IAI Applicability:

1. Designing for control loop stability between an Operator and machine can ensure that the proper controls and displays are embedded in an interface, to ensure that perceptual errors inherent in human-machine interaction are minimized.
2. The HGA hierarchy accounts for error correction at all levels of the goal hierarchy.
3. The primary output from a HGA analysis is a goal structure which provides interface guidance
4. Output from a HGA analysis will identify cognitive and perceptual information related to Output Interfaces and Input Interfaces.

Reference:

Hou, M. and Kobierski, R.D. (2006) Operational Analysis and Performance Modeling for the Control of Multiple Uninhabited Aerial Vehicles from an Airborne Platform. In Advances in Human Performance and Cognitive Engineering Research, 7, 267-282. Elsevier

Overview:

Detailed are the results from an operational analysis and simulation of the first phase of the DRDC project to investigate the efficacy of IAIs in an operational situation. The simulation was based on CF maritime aircraft operations in support of counter-terrorism activities.

Process of analysis:

A Hierarchical Goal Analysis was first performed to gain a more detailed understanding of the goals and tasks involved in controlling multiple UAVs from an airborne platform (CP140 aircraft). Methods of analysis are based on Perceptual Control Theory.

Operations/missions were analyzed as hierarchies of goals. These goals “are nested, sequenced or linked into logical networks”. The result of this analysis produced an HGA and network model (in IPME).

These network models are then used to model and predict operators’ performance (assignment of operators to tasks, and interactions). The goals and tasks identified by HGA can then be used to determine which tasks should be automated.

<u>Conclusions for IASs:</u>

1. The analysis revealed HGA can provide effective task models that can be used to improve the operations of a UAV crew with IAI.

4.2.4 Goal Directed Task Analysis

Goal Directed Task Analysis

<u>Reference:</u>

Jones, D.G. & Endsley, M.R. (2005). *Goad Directed Task Analysis*. In Hoffman, R., Protocols for Cognitive Task Analysis. State of Florida Institute for Human and Machine Cognition.

Endsley, M.R., Bolstad, C.A., Jones, D.G. & Riley, J.M. (2003). *Situation Awareness Oriented Design: From User’s Cognitive Requirements to Creating Effective Supporting Technologies.* Proceedings of the Human Factors and Ergonomics Society 47th Annual Meeting. Denver, Colorado.

Bolstad, C.A., Riley, J.M., Jones, D.G. & Endsley, M.R. (2002). *Using Goal Directed Task Analysis with Army Brigade Officer Teams.* Proceedings of the Human Factors and Ergonomics Society 46th Annual Meeting. Baltimore, MD.

Endsley, M. R., Bolté, B. & Jone, D. G. (2003). Designing for Situation Awareness. New York: Taylor and Francis

<u>Overview:</u>

A GDTA identifies the goals that must be achieved to accomplish a mission, the decisions that must be made to accomplish the goals, and the information that is required to support these decisions. Specifically, a GDTA outlines the information required to perform a job, and details the integration/combination of this information to formulate a decision. The process focuses on the information required to meet each goal; this process however does not focus on the means in which an Operator acquires the information.

A GDTA also defines the Situation Awareness requirements required to assess the information to determine how to achieve each goal for successful task completion. Once the information required to achieve a goal is identified, an evaluation of a pre-existing system can be conducted to determine whether the current design satisfies these needs, or a future system can be designed to account for these needs prior to system development.

Process:

A GDTA has three main components, including:

- Goals. Represent “higher-order” objectives related to a task, mission, or operation that are essential for successful job performance. The highest level goal represents the “overall goal” of the decision maker. Each main goal will have a varying number of sub-goals. Goals represent the cognitive effort required for successful task completion.
- Decisions. Represents the decisions that must be made to achieve a particular goal. Decisions represent the questions the decision maker must answer in order to achieve a goal.
- Situation Awareness Requirements. Represents the information required to answer the questions that form the basis of decisions.

A GDTA is documented according to two main structures:

- Goal Hierarchy. The overall goal is identified, from which the major goals are defined, along with the sub-goals required to successfully achieve each major goal.
- Relational Hierarchy. Outlines the relationship between the goals, the sub-goals, the decisions relevant to each sub-goal, and the SA requirements relevant for each decision.

Advantages:

1. Details the situational awareness requirements relevant to attaining each goal; and
2. Identification of the SA requirements will aid evaluation and the design of systems to ensure that the system supports an Operator in building and maintaining a high-level of SA.

Disadvantages:

1. Comprehensive method taking extensive time to complete;
2. Requires several sessions with subject matter experts to define the domain; and
3. Degree of subjectivity during the SME sessions.

IAI Applicability:

Aids the design of systems to support SA, by:

1. Identifying what information an Operator needs to know, providing guidance for designing a meaningful interface design;
2. Identifying functional grouping of information;
3. Guiding the relationship between information and decisions to support goals; and
4. Identifying critical cues required to direct shifts in task priority.

4.2.5 Cognitive Task Analysis

Cognitive Task Analysis

Reference:

Zachary, W., Ryder, J. & Hicinbothom, J. (n.d.). *Cognitive Task Analysis and Modeling of Decision Making in Complex Environments.* CHI Systems Incorporated, Lower Gwynedd, PA

Clark, R. & Estes, F. (1996). Cognitive Task Analysis. International Journal of Educational Research. 25(5), 403-417.

Clark, R., Feldon, D, van Merrienboer, J., Yates, K. & Early, S. (2006*). Cognitive Task Analysis*. Accessed at: http://www.cogtech.usc.edu/publications/clark_etal_cognitive_task_analysis_chapter.pdf, January 27, 2007.

Potter, S., Roth, E., Woods, D. & Elm, W. (2000). *Bootstrapping Multiple Converging Cognitive Task Analysis Techniques for System Design*. In Schraagen, J.M.C., Chipman, S.F., & Shalin, V. L. (Eds.), Cognitive Task Analysis. Mahwah, NJ: Lawrence Erlbaum Associates.

Overview:

Cognitive Task Analysis captures the experience, knowledge, and intuition of Subject Matters Experts by uncovering the cognitive skills and abilities required to complete a task proficiently. CTA concentrates on elements that cannot be directly observed such as difficult decisions, judgments, and perceptual skills. CTA identifies the demands that are placed on an operator's cognitive resources such as memory, attention, and decision making. Note that cognitive task analysis does not replace a behavioural task analysis, but rather supplements it. Concentrating on these elements provides a means to examine the processes underlying behaviour. This information allows a designer to focus on the system features that an operator will find most difficult to learn and therefore, the features that will likely create error.

Another characteristic of CTA is an attempt to describe the differences between novices and experts in the development of knowledge about tasks. CTA is able to elicit mental models used by experts, which provides a good basis for design and training.

CTA encompasses a collection of diverse approaches with very little connection or cohesiveness (Potter et. al., 2000). However, all CTA approaches share a common goal: to identify the cognitive activities that underlie task performance in order to improve individual and team performance (through correct design of training aids, OMIs, or decision aids) (Potter et. al., 2000).

Process:

CTA can be decomposed into three phases:

- Knowledge Elicitation. Extraction of information through in-depth interviews and observations, about cognitive events, structures or models. Interviews are conducted with Subject Matter Experts.
- Data Analysis. CTA practitioners use a variety of quantitative and qualitative analyses to complete data analysis. The goal is to simplify, abstract, and transform the data to develop explanations and meaning.
- Knowledge Representation. Process of displaying the data and depicting the relationship, explanations, and the meaning derived from data analysis.

Advantages:

1. CTA can boost human performance by guiding the development of tools and programs that support the cognitive processes required for a task.
2. Able to analyze task performance in situations that involve change, uncertainty and time pressure.
3. Aid experts in articulating knowledge that is generally difficult to verbalize.

Disadvantages:

1. CTA encompasses a collection of diverse approaches with very little connection or cohesiveness (Potter et. al., 2000).
2. CTA cannot be viewed as a standalone analysis. It needs to be an iterative process that learns from subsequent design activities (Potter et. al., 2000).

IAI Applicability:

1. CTA can boost human performance by guiding the development of tools and programs that support the cognitive processes required for a task.
2. CTA must work within a system development process and support critical system design issues (Potter et. al., 2000).

4.2.6 Team Cognitive Task Analysis

Team Cognitive Task Analysis

Reference:

Baker, D.P., Salas, E. & Cannon-Bowers, J.A. (n.d.). Team Task Analysis: Lost But Hopefully Not Forgotten. Accessed at: http://www.air.org/teams/publications/teamwork/team_task_analysis.pdf, January 27, 2007.

Blickensderfer, E., Cannon-Bowers, J. A., Salas, E., & Baker, D. P. (2000). *Analyzing Knowledge Requirements in Team Tasks*, In Schraagen, Chipman, & Shalin, Eds. Cognitive Task Analysis. Mahwah, NJ: Lawrence Erlbaum. 431-447.

Bowers, J., Baker, D.P., & Salas, E. (1994). *Measuring the Importance of Teamwork: The Reliability and Validity of Job/Task Analysis Indices for Team-Training Design*. Military Psychology, 6(4), 205-214.

Brenner, T., Sheehan, K., Arthur, W. & Bennett, W. (n.d.). *Behavioural and Cognitive Task Analysis Integration for Assessing Individual and Team Work Activities*. Accessed at: http://www.internationalmta.org/1998/9847d.html, on January 27, 2007.

Darvill, D., Kumagai, J. & Youngson, G. (2006). *Requirements Analysis Methods for Complex Systems.* Technical Report to Defence Research & Development Canada Valcartier (CR 2005-076).

Harder, R. & Higley, H. (2004). *Application of Thinklets to Team Cognitive Task Analysis*. Proceedings of the 37th Hawaii International Conference on System Sciences.

Overview:

Team Cognitive Task Analysis is an extension of Cognitive Task Analysis, with emphasis on teamwork requirements. Current methods of task analysis fail to capture team characteristics such as interdependence and co-operation. Applying a method of analysis designed for individuals to teams is not sufficient for obtaining true understanding of how a team works.

Team CTA methods view the team as an intelligent entity, and attempt to identify the cognitive processes required by team dependent tasks (Harder & Higley, 2004). Team CTA captures the cognitive processes of a team, and focuses on the way a team coordinates the understanding of the different members and synthesizes the task elements (Harder & Higley, 2004). This method emphasizes the importance of communication and situation awareness and provides assistance in diagnosing and treating existing problems in teamwork to ensure efficient and effective team functioning.

Team CTA provides the foundation for many human resource functions in the context of teamwork including team task design, team composition, team training and team composition (Brenner et. al.). Team CTA also provides insight into critical team task elements.

Team task analysis refers not only to an analysis of a team's tasks, but also to a comprehensive assessment of a team's teamwork requirements (i.e., knowledge, skill, ability, and attitude requirements). Team task analysis is important because it forms the foundation for team design, team performance measurement, and team training. Essentially, it is the building block for all "team" resource management functions (Baker et. al.).

Darvill et. al., (2006) identifies a list of cognitive processes that are important in the analysis of teams, including:

- Control of attention;
- Shared situation awareness;
- Shared mental models;
- Application of strategies and heuristics to make decisions; and,
- Meta-cognition or how a team is able to monitor itself and determine when the team is faced with difficulties or challenges.

<u>Process:</u>

Although there is much research invested in the application of Task Analysis techniques, there is relatively little guidance in literature regarding how to conduct task analyses for teams (Bowers et. al., 1994).

Currently, the primary method for conducting team cognitive task analysis has been to use techniques from job analysis to determine team task and cognitive skill requirements (Baker et. al.). A literature review also conducted by Baker et. al., (n.d.) provided examples of the following team cognitive task analysis methods: Critical Incident Technique, Task Important Indices, Team Task Inventory, and Team Characteristic Questionnaires. Despite the Team CTA technique used, the results of the assessment should provide a comprehensive evaluation of a team, providing information on the tasks performed in terms of communication, cooperation, knowledge, attitude and skill requirements.

Darvill et. al., (2006) also indicates that Team CTA is lacking support in literature. However, the following methods to Team CTA were identified:

- Team Audit. Elicits knowledge and skills from team members, and elicits examples from actual events.
- Team Critical Decision Method (Team CDM). Four information gathering sweeps are conducted to reveal critical cognitive elements related to team incidents.
- Distributed Team Assessment Method (DTAM. Method used with a widely separated team that was involved in the same incident. The objective of this method is to identify functions, goals, and communication links in order to reveal overlaps or gaps in roles and functions. This will identify goal conflicts and will provide the opportunity to improve information exchange.
- Decision Requirements Exercise (DRE). Decision requirements table to determine the critical

decisions and judgements a team made to perform a task.

- Wagon Wheel Method (WWM). Snapshot of team communication links and the nature of their communications.

Advantages:

1. The output of Team CTA provides input to team design, team performance measurement, and team training.
2. The output of Team CTA provides results that can act as input to other analysis methods.
3. Useful for analysis of complex multi-person judgements and decision-making.
4. Aids the design of systems and interfaces that are used for teams.

Disadvantages:

1. Extensive time and expertise required.
2. Common challenges are apparent when conducting group interviews.
3. Little research regarding the application of Team CTA techniques.
4. Application of an analysis method to teams designed for individuals is not sufficient for true understanding of how a team works.

IAI Applicability:

1. Views a team as an intelligent entity, and attempts to identify the cognitive processes required by team dependent tasks.
2. Captures the cognitive processes of a team, and focuses on the way a team coordinates the understanding of the different members and the synthesis of task elements.
3. Used to identify information, cues, and strategies required to make key decisions.

4.2.7 Applied Cognitive Task Analysis

Applied Cognitive Task Analysis	

Reference:

Eddy, M., Kribs, H. & Cowen, M. (1999). *Cognitive and Behavioural Task Implications for Three-Dimensional Displays used in Combat Information/Direction Centers*. Technical Report 1792.

Militello, L., Hutton, R., Pliske, R., Knight, B. & Klein, G. (1997). *Applied Cognitive Task Analysis Methodology. Navy Personnel Research and Development Center*. San Diego, CA.

Militello, L. & Hutton, R. (1998). *Applied Cognitive Task Analysis: A Practitioner's Toolkit for Understanding Cognitive Task Demands*. Ergonomics 41(11), 1618-1641.

Overview:

ACTA is a streamlined method of Cognitive Task Analysis. The basis of ACTA's development was to develop techniques that would enable systems and instructional designers to elicit critical cognitive task components from Subject Matter Experts. The ACTA was developed to allow cues and sources of information to be derived within the context of Situation Awareness. ACTA analyses an individual's mental representation of SA, and compares the differences between novice and expert processes (Eddy et. al., 1999).

Process:

ACTA consists of three interview methods that help the practitioner to extract information about the cognitive demands and skills required for a task.

- Task Diagram. The Task Diagram provides an overview of a task and identifies a task's cognitive elements. The development of a Task Diagram is facilitated through a preliminary interview, providing a surface-level view of the task's cognitive elements. This allows the interviewer to identify the most difficult and relevant cognitive elements that should be the focus of interviews during the Knowledge Audit and Simulation Interview stage. The Subject Matter Experts decompose a task into sub-tasks. After the sub-tasks have been identified, the SME identifies the sub-tasks that require cognitive skill.
- Knowledge Audit. The Knowledge Audit captures the most important aspects of expertise. The Audit identifies how expertise is used, and provides examples based on true experience. The Audit is based on knowledge categories that form the basis of expertise, such as: diagnosing and predicting, situation awareness, perceptual skills, improvising, metacognition, recognizing anomalies, and compensating for equipment limitations (Militello et. al., 1997). The interviewer uses a set of probes that are designed to describe types of domain knowledge or skill. The goal is to use these probes to determine the nature of these expertise skills, the tasks where these skills are implemented, along with what types of strategies are used. The output of the Knowledge Audit is a table which provides an inventory of task-specific expertise. The table outlines when experience, expertise, and strategies were required for difficult situations, and why these situations may pose a challenge to less-experienced Operators (Militello et. al., 1997).
- Simulation Interview. The purpose of the Simulation Interview is to identify a SME's cognitive processes within the context of an incident. The interview presents a challenging scenario to the SME, and the SME is required to identify major events, judgment and decision making requirements, troubleshooting diagnosis, situation assessment, critical cues, and selection of courses of action.

Advantages:

1. ACTA techniques are easy to use, flexible, and provide clear output.
2. Identifies where a system's design must support human problem-solving and decision-making by assessing complex tasks that require a high degree of cognitive skill.

Disadvantages:

1. Although ACTA elicits important cognitive information, there is a trade-off when using a streamlined approach; the more streamlined and proceduralized CTA techniques become, the less powerful they are (Militello & Hutton, 1998).
2. ACTA techniques may gather less comprehensive information than more systematic techniques.

IAI Applicability:

1. ACTA provides data that translates more directly into applied products such as improved training scenarios or interface recommendations.
2. Allows systems designers to elicit and represent critical cognitive components of skilled task performance, and the means to transform these data into design recommendations.

3. ACTA techniques were developed to elicit critical cognitive task components from Subject Matter Experts.

4.2.8 Cognitive Work Analysis

Cognitive Work Analysis	

Reference:

Darvill, D., Kumagai, J. & Youngson, G. (2006). *Requirements Analysis Methods for Complex Systems.* Technical Report to Defence Research & Development Canada Valcartier (CR 2005-076).

Fidel, R. & Pejtersen, A. (2004a). Cognitive Work Analysis.

Fidel, R. & Pejtersen, A. (2004b*). From information behaviour research to the deign of information systems: the Cognitive Work Analysis Framework*. Information Research, 10(1).

Lui, F. & Watson, M. (2002). *Mapping Cognitive Work Analysis (CWA) to an Intelligent Agents Software Architecture: Command Agents*. Proceedings of the Defence Human Factors Special Interest Group (DHFSIG). DSTO Melbourne, Australia.

Naikar, N. (2006). *An Examination of the Key Concepts of the Five Phases of Cognitive Work Analysis with Examples from a Familiar System*. Proceedings of the Human Factors and Ergonomics Society 50th Annual Meeting. San Francisco, CA.

Rasmussen, J., Pejtersen, A. & Schmidt, K. (1990). *Taxonomy for Cognitive Work Analysis.* RISO National Laboratory, Cognitive Systems Group, Denmark.

Overview:

CWA is useful for the study of human-information interaction and for the design of information systems and services. The approach analyzes the work individuals perform, the tasks they perform, the decisions that they make, their information behaviour, and the context in which their work is performed. The purpose of this approach is to facilitate systems design, and facilitate the analysis of tasks and context simultaneously.

CWA is a work-centred formative approach to work analysis which focuses on how work can be performed. The approach recognizes that workers have many options in terms of what work to perform, when to perform the work, and how to perform the work. (Naikar, 2006). Thus, CWA identifies the constraints that shape the work and information behaviour.

CWA considers people who interact with information involved in their work-related activities (i.e., ecological aspects), rather than "users" of systems. CWA views human-information interaction in the context of human work activities. Fidel & Pejtersen (n.d.) indicate that in order to design systems that work harmoniously with humans, the following must be defined:

- The work individuals perform;
- The individuals' information behaviour;
- The context in which the individuals work; and,
- The reasons for their actions.

Process:

CWA consists of the following five stages.

- Work Domain Analysis (WDA). Focuses on the purposive (reasons for which a system exists) and physical (resources that are available) environments in which workers operate (Naikar, 2006). The main modeling tool is the abstraction-decomposition space (ADS).
- Control Task Analysis (ConTA). This stage focuses on what needs to be done in a work domain. The ConTA identifies the activity that is necessary to achieve the objectives of a system with a given set of physical resources. According to Naikar (2006), ConTA has three key concepts:
    - Recognizes that the same goal can be accomplished in different ways depending on the situation;
    - An activity can be characterized as a set of work situations or work functions; and,
    - An activity can be further characterised according to decision making functions or control tasks.

  The tool used during this stage is a decision ladder.
- Strategies Analysis. This stage identifies different strategies for accomplishing an activity; thus, Strategies Analysis is focussed on how an activity can be completed. According to Naikar (2006) Strategies Analysis has four key concepts:
    - Concerned with general categories of cognitive procedures;
    - Several strategies are often available to complete an activity;
    - Workers will often utilize more than one strategy when completing an activity; and
    - The range of strategies that are possible should be identified as opposed to only the range of strategies that are used.
- Social Organization and Cooperation Analysis (SOCA). Identifies who completes the work, and how the work is shared and coordinated. According to Naikar (2006) SOCA has four key concepts:
    - Flexible organizational structure that can be adapted to local contingencies are essential for dealing with unanticipated events;
    - Examines how the work demands of a system may be distributed across workers as a result of applying various criteria;
    - Concerned with the form of communication or social organization that may be adopted for coordination in a system; and
    - Organizational structures in many systems are generated in real time by multiple workers responding to a local context.
- Worker Competencies Analysis (WCA). Identifies the competencies that a worker is required to adapt to the work requirements of a system. According to Naikar (2006) SOCA has five key concepts:
    - The competencies that a worker requires is based on the requirements identified during Stages 1-5;
    - There are three levels of cognitive control that a worker can use to perform an activity: skill-based, rule-based, and knowledge based;
    - The level of cognitive control that is implemented depends on how the worker

interprets the information in the environment; and

- The level of cognitive control that is implemented also depends on how the information is presented to a worker; and
- Workers will implement lower levels of cognitive control more quickly, effectively, and effortlessly than higher levels of cognitive control.

Advantages:

1. Results from CWA can be transferred directly to design requirements.
2. Accounts for the role of the workers in complex systems.
3. Focuses on analysing the environment.
4. The model provides traceability of decision making in a organisational structure (Lui & Watson, 2002)
5. The model provides a link between the abstract functions in the higher hierarchy level and the plans/courses of action in the lower hierarchy level (Lui & Watson, 2002).

Disadvantages:

1. Complex method requiring considerable expertise.
2. Extensive time required to learn and use.
3. Difficult to define and map the system on all five stages.
4. Little practical difference between CWA and ACWA. Many times, CWA will only be applied using the first few stages, which resembles more of the ACWA process.
5. CWA is more of an academic endeavour with more attention being placed on completing the process as opposed to using the analysis to drive design and develop design concepts (Darvill et. al., 2006).

IAI Applicability:

1. Identifies the constraints on information seeking, including the individual resources and the external environment.
2. CWA investigates the information behaviour in context. Therefore the results are valid for the design of information systems in the context investigated, rather then for the design of general information systems (Fidel & Pejtersen (n.d.).
3. The framework facilitates an in-depth examination of the various dimensions of a context. A study of a particular context is, therefore, a multi-disciplinary examination with the purpose of understanding the interaction between people and information in the work context (Fidel, R. & Pejtersen, A. (n.d.).
4. Provides a structure of human-information interaction analysis, rather than subscribing to specific theories or models (Fidel & Pejtersen (n.d.).
5. Workers will implement lower levels of cognitive control more quickly, effectively, and effortlessly than higher levels of cognitive control. Interfaces should therefore present information that allows workers to rely on lower levels of cognitive control (Naiker, 2006).

Reference:

Naikar, N. (2006). An examination of the key concepts of the five phases of cognitive work analysis with examples from a familiar system. Proceedings of the 50th Human Factors and Ergonomics Society Conference, San Francisco, CA

Overview:

This paper examines the concepts of all five phases of CWA with examples from a single 'system', a home. A home is described as a highly familiar system that is characterized primarily by social or intentional constraints. The examples in this paper complement the case study provided by Vicente (1999) of DURESS, a thermo-hydraulic micro world simulation that is defined largely by physical or causal constraints. In addition, this paper examines several issues relating to the later phases of CWA, including whether or not they are useful or unique, evaluates their relationship to other approaches for work analysis, and identifies methodological shortcomings.

Conclusions for IASs:

1. CWA is a single approach to work analysis that generates an integrated, multi-faceted description of a system.
2. Alternative techniques can be used in some or all of the phases of CWA but it is important to ensure that alternative techniques are consistent with CWA.
3. There are some methodological issues with the concepts of the phases of CWA. For instance, it is not clear how to identify the range of strategies that are possible as opposed to those that are currently being used by workers. This problem is exacerbated when the system of interest is a future, first-of-a-kind system.

4.2.9 Applied Cognitive Work Analysis

Applied Cognitive Work Analysis

Reference:

Darvill, D., Kumagai, J. & Youngson, G. (2006). *Requirements Analysis Methods for Complex Systems.* Technical Report to Defence Research & Development Canada Valcartier (CR 2005-076).

Elm, W. (2002). Applied Cognitive Work Analysis. ManTech Aegis Research Corporation. Pittsburgh, PA

Means, C.D., Darling, E. & Perron, J. (2004). *Applying Cognitive Work Analysis to Time Critical Targeting Functionality*. MITRE Technical Report, MITRE, Bedford, Massachusetts.

Potter, S., Elm, W., Roth, E., Gualtieri, J. & Easter, J. (2001). *Bridging the gap between Cognitive Analysis and Effective Decision Aiding.* Accessed at: http://mentalmodels.mitre.org/cog_eng/reference_documents/Bridging%20the%20Gap--revised2.pdf, January 27th, 2007.

Potter, S., Roth, E. & Woods, D. (2001). *The Development of a Computer-Aided Cognitive Systems Engineering Tool to Facilitate the Design of Advanced Decision Support Systems*. United

States Air Force Research Laboratory: AFRL-HE-WP-TR-2001-0125.

Roth, E. (n.d.). Trends in Cognitive Analysis: Codifying Methods and Illustrating Benefits. CTA eMagazine. Accessed at: http://www.ctaresource.com/eMagazine/, January 27th, 2007.

Overview:

ACWA is a streamlined version of CWA that represents the results of knowledge elicitation using a goals-means decomposition, which is a modified version of Rasmussen's Functional Hierarchy (Darvill et. al., 2006). The objective of ACWA is to facilitate the incorporation of cognitive task analysis outputs into the he design of decision support software.

The goal-means decomposition focuses explicitly on the goals to be accomplished in the work domain (CWA), the relationships between goals, and the means to achieve goals, including the decisions required, and the information required to make those decisions.

ACWA provides a practical, step-by-step approach that links the demands of the domain as revealed by the cognitive analysis through the identification of visualizations and decision-aiding concepts that will provide effective support.

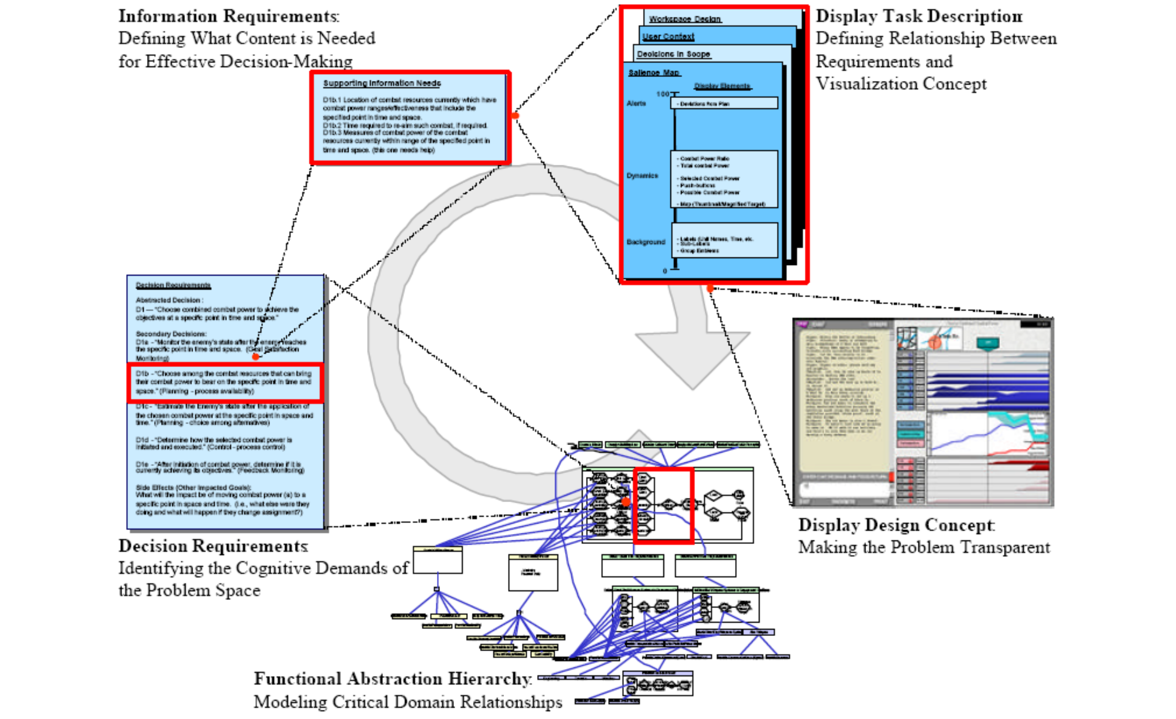
Process:

ACWA includes the following steps (Roth, n.d.):

- Functional Abstraction Network (FAN). Captures essential domain concepts and relationships that define the problem-space;
- Cognitive Work Requirements. Overlaid on the functional model as a way of identifying the cognitive demands / tasks / decisions that arise in the domain and require support;
- Information / Relationship Requirements. Support the cognitive work identified in the "Cognitive Work Requirements";
- Representation Design Requirements. Requirements that define how the information / relationships should be represented to practitioner(s) to most effectively support the cognitive work; and
- Presentation Design Concepts. Provide physical embodiments of the representations specified in the previous step (e.g., rapid prototypes that embody the display concepts). The phrase 'presentation design' is used to emphasize that the resulting 'displays' need not be visual; they can be auditory, tactile, or multi-modal.

In the ACWA analysis and design approach, each step is associated with a design artifact that captures the results. These design artifacts form a continuous design thread that provides a principled, traceable link from cognitive analysis to design.

The figure below provides a sequence of analysis and design steps that are used to create a continuous design thread that starts with a representation of domain concepts and relationships through the development of decision support requirements to creation of visualization and aiding concepts and rapid prototypes with which to explore the design concepts (Potter et. al., 2001).



Advantages:

Roth (n.d.) outlines the following strengths for the ACWA method:

1. Identification of high-level domain goals (FAN) allows for development of novel visualization of the non-physical abstractions, to provide more effective support of individual and collaborative decision making and planning.
2. Organizing operator cognitive requirements around nodes in the FAN, rather than organizing requirements around pre-defined task sequences (as in traditional approaches to task analysis) results in decision-support systems that have a decision-centered perspective, and are thus, able to support performance in unanticipated situations as well as expected situations.
3. Providing a step-by-step set of linked processes from cognitive analysis to design ensures traceability of design elements to cognitive requirements they are intended to support.
4. Design artifacts capture the results at each stage of the process.
5. Application of this method leads to the development of a prototype.

Disadvantages:

1. Complex method requiring training and experience.
2. Little practical difference between CWA and ACWA.
3. ACWA has few practitioners, and lacks support tools.

IAI Applicability:

1. Knowledge acquisition is tightly coupled to modeling of the work domain as well as the

development of Decision Support Systems.

2. The approach is able to yield novel decision support concepts that were finely tuned to the cognitive work requirements of the domain (Roth, n.d.).
3. Critical decisions, as well as the information required to support these decisions are overlaid on the nodes in the FAN (Darvill et. al., 2006).
4. The application of this method provides a “decision centred” design specification.

Reference;

Paradis, S., Breton, R., Elm, W.C., and Potter, S.S. (2002). A Pragmatic Cognitive System Engineering Approach to Model Dynamic Human Decision-Making Activities in Intelligent and Automated Systems. In Proceedings of RTO Human Factors and Medicine Panel (HFM) Symposium held in Warsaw, Poland, 7-9 October 2002

Overview:

This paper briefly overviews the Cognitive System Engineering (CSE) analysis methodology. The CSE approach, known as the Applied Cognitive Work Analysis (ACWA), is used to investigate decision support R&D efforts. Refer to article for details on how to conduct ACWA.

Conclusions for IASs:

1. Authors report that CWA is well suited to deal with design issues related to decision support but if used in full scale (that is, all sequential CWA phases are used) for a small problem, it is time consuming and very expensive to conduct.
2. The ability to convert requirements into a sensory presentation (e.g., design of auditory and visual features, etc.) requires considerable skill beyond cognitive work analysis. It requires an understanding of human perception and its interaction with the various presentation techniques. The authors claim that the designer must really understand what presentation characteristics implicitly specify the interaction with the operator’s perception.
3. The ACWA was found to be opportunistic and flexible when new knowledge elicitation activities arise, and when the scope of the project itself expanded significantly.
4. The ACWA approach in concert with a systematic documentation methodology (e.g., FAN) was found very useful in the ATAC project. The documentation served as the main reference material to conduct/structure interviews and training sessions with subject matter experts. The documentation was to also used during brainstorming design meetings and was helpful for progress review meetings.

4.3 Design Methodology

The section reviews the following design methodology:

- Joint Application Design / Development (JAD);
- US Department of Defence Architectural Framework (DoDAF);

- Explicit Models Design; and,
- Ecological Interface Design.

4.3.1 Joint Application Design / Development

Joint Application Design / Development	

Reference:

Cline, A. (n.d.). Joint Application Development (JAD) for Requirements Collection and Management. White Paper (Carolla Development) http://www.carolla.com/wp-jad.htm. Accessed January 28th, 2007.

Darvill, D., Kumagai, J. & Youngson, G. (2006). Requirements Analysis Methods for Complex Systems. Technical Report to Defence Research & Development Canada Valcartier (CR 2005-076).

Klenc, M.W. (2001). *The effective methodology for systems requirement analysis*. (http://www.umsl.edu/~sauter/analysis/488_f01_papers/Klenc/). Accessed January, 28th, 2007.

Yatco, M. (1999). *Joint Application Design/Development.* http://www.umsl.edu/~sauter/analysis/JAD.html. Accessed January 28th, 2007.

Overview:

Joint Application Development is a process originally developed for designing a computer-based system. JAD was used to promote the interaction between IT professionals and operators to facilitate an agreement on requirement and design specifications. JAD is defined as a management process that combines operators and computer specialists to participate in an extremely focused team collaborative workshops, which allows information systems for the operator to be integrated in a shorter time frame (Klenc, 2001). The approach was designed to increase development time, and improve the quality of the 'end-product' by incorporating operators at the beginning of the development life-cycle.

Process:

The JAD method centers on a structured workshop session. The workshop focuses on integrating key operators (stakeholders) and systems professionals together to resolve issues that are inhibiting the design process. Workshops are effective at all levels: enterprise, business area, application, and project management.

Process modeling is used to prepare for a JAD session. Mock-ups and prototypes can also be used to validate earlier results. Preparation for a JAD session may include elements of other methods focusing on Mission, Function, and Task Analyses to develop an understanding of the topic area. The JAD process acknowledges and outlines goals, terminology, processes, requirements, and objectives during the workshop.

JAD workshops are held early in the development life-cycle to define objectives and decompose the domain into smaller functions, thus defining boundaries and scope. The goal is to minimize documentation and put critical information and knowledge in an explicit format to be reused by other team members (Darvill et. al., 2006).

Key players that may be involved in the workshop include:

- Facilitator. Unbiased leader who has no ties to the project;
- Documentation Expert. Documents the decisions and issues;
- Executive Sponsor. Charters the project (the system owner);
- Project Manager. Responsible for the project;
- Business Users. Intended operators of the system being designed (i.e., end-users);
- Systems Experts. Provide inputs in terms of the system constraints; and
- Outside Experts. Business consultants or technology consultants who provide expertise.

Advantages:

1. Effective technique for building operator commitment to the success of application systems through active participation in the analysis of requirements and the specification of the system design.
2. Extensive operator involvement in systems requirements definition.
3. JAD results can be used as input to other methods (e.g., knowledge elicitation technique).
4. Workshops facilitate a common understanding amongst designers, operators and stakeholders.
5. Decisions (and reasoning for decisions) are well documented.

Disadvantages:

1. Extensive preparation.
2. Focuses on system objectives and process outcomes, as opposed to the cognitive components of the processes.
3. Workshops can be dominated by individuals.
4. Participants may be varied in terms of their status within the company (e.g., senior managers versus mid-level employees), impacting the amount of participation from individuals.

IAI Applicability:

1. Identifies the system requirements from an operator perspective.
2. Drives top-priority requirements and interface concepts.

4.3.2 US Department of Defence Architectural Framework

US Department of Defence Architectural Framework	
Reference: Darvill, D., Kumagai, J. & Youngson, G. (2006). Requirements Analysis Methods for Complex Systems. Technical Report to Defence Research & Development Canada Valcartier (CR 2005-076). US Department of Defence Architectural Framework Working Group. (2004). *DoD Architecture Framework*	

– *Volume I: Definitions and guidelines (Version 1),* February 9, 2004.

US Department of Defence Architectural Framework Working Group. (2004). *DoD Architecture Framework – Volume II: Product descriptions (Version 1),* February 9, 2004.

Wood, W.G., Barbacci, M. Clements, P., Palmquist, S., Ang, H., Bernhardt, L., Dandashi, F., Emery, D., Sheard, S., Uzzle, L., Weiler, J. & Krummenoehl, A. (2003). *DoD Architecture Framework and Software Architecture Workshop Report.* Technical Report: CMU/SEI-2003-TN-006.

Wood, W. & Cohen, S. (2003). DoD Experience with the C4ISR Architecture Framework. Architecture Tradeoff Analysis Initiative. Technical Note CMU/SEI-2003-TN-027.

<u>Overview:</u>

One of the key means for ensuring interoperable and cost-effective military systems was to establish comprehensive architectural guidance for all of the Department of Defense (DoD). Thus, DoD policy highlights the use of architectures for understanding the DoD as an enterprise; one of the key developments is the Department of Defense's Architecture Framework. DoDAF was developed to provide guidance in describing both war fighting operations and business operations and processes.

DoDAF was developed to ensure that architecture descriptions developed by the DoD commands, services, and agencies are interoperable across each organization's operational, systems, and technical architecture views, and also interoperate across joint and combined organization boundaries (US DoDAF WG, 2004).

The framework provides rules and guidance for developing and presenting architecture descriptions. DoDAF defines three views of architecture descriptions: Operations View (OV), Systems View (SV); and Technical Standards View (TV). The All-DoD Core Architecture Data Model (CADM) defines the entities and relationships for architecture data elements (US DoDAF WG, 2004).

<u>Process:</u>

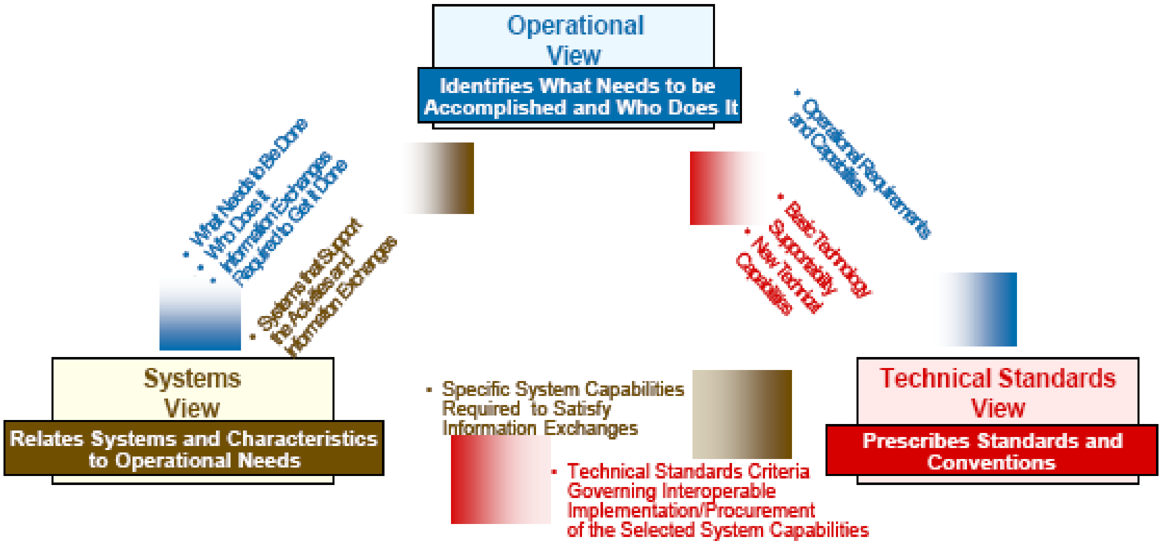
According to US DoDAF WG (2004), the architecture description views are described as follows:

The OV describes the tasks and activities, operational elements, and information exchanges required to achieve DoD missions; mission can include both war fighting and business processes. The OV contains graphical and textual products that identify the operational nodes and elements, tasks and activities, and information flows. It outlines the type of information exchanged, exchange frequency, and information exchanges that support tasks and activities.

The SV is also a set of graphical and textural products that describe systems supporting DoD functions (war fighting and business). The SV coordinates systems resources to the OV, which support the operational activities, and facilitate the exchange of information among operational nodes.

The TV is a rule set which directs the arrangement, interaction, and interdependencies of system elements, ensuring that a system satisfies operational requirements. The TV consists of a collection of technical standards, implementation conventions, standards options, rules, and criteria organized into profiles that govern systems and system elements.

A DoDAF compliant architecture must incorporate explicit linkages among its various views. The three views and their interrelationships provide the basis for measuring system interoperability and performance, as well as their impact on mission and task effectiveness.



Fundamental linkages among DoDAF views (US DoDAF WG 2004).

<u>Advantages</u>:

1. Comprehensive architecture that provides extensive details of a system's components.
2. Able to identify multiple players within a system, which can result in a systems of systems analysis.
3. Can support the System Engineering approach to provide a more rigorous method for generating requirements.
4. The information gathered to develop the DoDAF frameworks can be used as valuable data input for Human Factors and Cognitive Engineering analysis techniques such as: **Mission, Function, & Task Analysis, Hierarchical Goal Structure; and Cognitive Work Analysis.**

<u>Disadvantages</u>:

1. Describes what types of information need to be captured but it does not detail how that information should be captured.
2. Although DoDAF documents system architectures, it does not address software architectures. Software views are sometimes needed to supplement DoDAF representations.
3. Complex method, involving extensive cost, expertise, and time.
4. No specific human-related views within the framework.

<u>IAI Applicability</u>:

1. Applicable across: concept design, requirements analysis, function analysis, interface development, team development, performance, workload, and training.

4.3.3 Explicit Models Design

Explicit Models Design

Reference:

Edwards, J.L. (2006). *Cognitive Style Assessment and Adaptation to User Style in the LOCATE Worksapce Layout Design Tool.* Defence Research & Development Canada Toronto (CR 2006-089).

Edwards, J. L. (2004). *A Generic, Agent Based Framework for the Design and Development of UAV/UCAV Control Systems*. Defence Research & Development Canada Toronto, Toronto, Ontairo, Canada.

Mason, J.A. & Edwards, J.L. (1988). Explicit Models in Intelligent Interface Design. ACM SIGCHI Bulletin, 20(1).

Overview:

The objective of Explicit Models Design is to identify and define the knowledge required by intelligent systems. EMD characterizes and models knowledge according to five distinct, interacting models (Edwards, 2004), including:

- Task Model;
- User Model;
- System Model;
- Dialogue Model; and
- World Model.

Plan recognition and plan generation are also two processes that operate within the EMD framework.

Process:

The Task Model contains knowledge pertaining to the tasks an operator performs; this knowledge is represented as a hierarchy of actions, goals and plans. Satisfying low-level goals allows for the attainment and achievement of higher level goals, commonly known as tasks. The pathway from a low-level goal to a high-level goal identifies and defines a plan for attaining that goal.

The System Model is also characterized by a goal hierarchy, containing a description of the tasks, goals, and plans that a system completes to support an operator; these goals are System Support Goals. When multiple system agents are involved, the System Model will be comprised of a distinct goal hierarchy for each agent. The System Model defines the level of assistance provided by the system to aid an operator.

The User Model is built from information volunteered by an operator, results of system requests , and from system monitoring of operator’s activities. The System Model is built to facilitate the system’s recognition of each operator’s unique profile.

The Dialogue Model identifies the communication and interaction that takes place between the operator, system, and other system agents. The Dialogue Model must be built to allow feedback between agents.

The World Model defines the external world, according to the objects that exist in the world, their properties, and the rules that govern them. These rules can be varied, such as physical rules, psychological rules, and cultural rules.

Plan Recognition involves the recognition of operator plans to enhance the system's "awareness" of the task/goal an operator is trying to accomplish, and providing assistance to support that plan.

Plan Generation pertains to the system's ability to develop and provide a strategy for assisting an operator in accomplishing a specific task/goal. Plan Generation is based on: the System Model knowledge of a hierarchy of available support goals and plans; Task Model knowledge of an operator's current goals and plans; and a User Model knowledge of an Operator's preferences and abilities.

Plan recognition and plan generation can be associated with activities in the Perceptual Control Theory.

Advantages:

1. Supports multi-agent system development.
2. Incorporates the concept of feedback, defining the support required between the operator and the system, allowing one agent to convey its goals, plans and knowledge to another agent.

Disadvantages:

1. Difficulty in characterizing the knowledge according to one of the five models.
2. Difficulty in coordinating the interaction of knowledge between models.

IAI Applicability:

Mason & Edwards (1988) identify the following issues pertaining to the design of intelligent interfaces:

1. Constraints on human processing, such as attention span, should be accommodated for in the design;
2. An intelligent system should be a partly autonomous agent;
3. An Intelligent system should be designed to incorporate explicit active models of tasks, operators, the system, and the dialog with the operator;
4. An intelligent system should model operators in terms of their individual characteristics; and,
5. Additional IAI applicability includes:
    - Supports multi-agent system development;
    - Recognizes Operator and System roles as agents and allows for the involvement of both multiple human operators and system agents, each represented by its own User or System Agent Model (Edwards, 2004); and,
    - External agents are recognized as also possibly supporting the goals of both human operators and system agents.

4.3.4 Ecological Interface Design

Ecological Interface Design

Reference:

Edwards, J. L. (2004). *A Generic, Agent Based Framework for the Design and Development of UAV/UCAV Control Systems*. Defence Research & Development Canada Toronto, Toronto, Ontairo, Canada.

Hou, M. (2003). *A Framework for Optimizing Operator-Agent Interaction*. Technical Report: Defence Research & Development Canada Toronto.

Roth, E.M., Patterson, E.S. & Mumaw, R. J. (2001). Cognitive Engineering: Issues in User-Centered System Design. In J.J. Marciniak (Ed.), Encyclopedia of Software Engineering, 2nd Edition. New York: Wiley-Interscience, John Wiley & Sons.

Vicente, K.J. & Rasmussen, J. (1992). Ecological interface design: theoretical foundations. *IEEE TransActions on Systems, Man, and Cybernetics*, Vol. SMC-22, 589-606.

Overview:

Ecological Interface Design is an interface design approach that incorporates elements from ecological psychology, particularly with emphasis on the importance of considering the interaction of humans with their environment (Vicente & Rasmusen, 1992). EID examines how humans interact with their surroundings, taking into account both physical and cognitive factors, in the context of the complex system under control (Edwards, 2004). EID provides interface design guidance, with the intent of aiding the design of interfaces that are intuitive and flexible for the operators, to ensure optimal usability and safety. EID also incorporates cognitive factors in interface design guidance to ensure that interface designs also account for how Operators make decisions and analyse problems.

Process:

Two theoretical concepts underlie the EID framework:

- Abstraction Hierarchy. Means-end hierarchy that describes the properties of a complex work domain (Edwards, 2004). The hierarchy includes the following five levels (based on process control):
    - Functional Purpose. High-level purpose for which the system was designed;
    - Abstract Function. Causal structure of the system;
    - Generalised Function. Decomposition of sub-functions that enable the high-level functions;
    - Physical Function. Characteristics of system components and their connections; and
    - Physical Form. Physical appearance and location of components.

  System functions are described and characterized according to goals. Moving upwards through the levels identifies the broad goals that the system achieves. Moving downwards through the levels identifies the method(s) to achieving those goals. Edwards (2004) indicates that this “goal-based” structure has the potential to dovetail with the goal and plan hierarchy of *Explicit Models Design.*

- Skills, Rules, and Knowledge Taxonomy. Taxonomy of three principles that correspond to three levels of cognitive control. Vicente & Rasmussen (1992) describe these principles as the following:
  - Skill-based behaviour. To support interaction via time-space signals, the Operator should be able to act directly on the display, and the structure of the displayed information should be isomorphic to the part-whole structure of movements (actions). This rule corresponds to principles of direct manipulation; the interface should represent an Operator's mental model of the system, and the Operator should have control over this representation.
  - Rule-based behaviour. Provides a consistent one-to-one mapping between the work domain constraints and the cues or signs provided by the interface. This rule indicates that the interface should provide representations for all relevant constraints in the system.
  - Knowledge-based behaviour. Represents the work domain in the form of an abstraction hierarchy to serve as an externalised mental model that will support knowledge-based problem solving. This rule indicates that the interface represent the work domain at all levels of abstraction.

Advantages:

1. Approach accommodates both perceptual and analytical cognitive processing.
2. Accounts for perceptual and analytical cognitive processing which facilitates optimal interaction between system and operator agents.
3. EID was developed to ensure the safety and reliability of complex systems.

Disadvantages:

Edwards (2004) outlines the following disadvantages of the EID approach:

1. Does not address implications of automation, such as boredom and fatigue, that can result from repeated applications of rule-based and skill-based behaviours; and
2. Does not address how to detect when Operators would become over-reliant on perceptual behaviours and fail to use knowledge-based skills in situations where they are required.
3. Little experimental research to support EID approach.

IAI Applicability:

1. Accounting for perceptual and analytical cognitive processing facilitates optimal interaction between system and operator agents, by accounting for both skill and rule based behaviours.
2. EID specifically designs for complex systems; and
3. Provides effective mappings between domain goals and OMI characteristics.

4.4 Summary

Tables 10, 11 and 12 summarise the analysis methodologies and Tables 13 and 14 summarise the design methodologies. The methodologies are described in terms of their advantages and disadvantages, and their applicability to intelligent adaptive systems.

	Hierarchical Task Analysis	Mission Function Task Analysis	Hierarchical Goal Analysis
Advantages	Cost efficient task analysis method. Easy to learn and apply. Results can provide the input to a variety of other analyses. Provides an analytical framework for designers.	Relatively easy method for Subject Matter Experts and analysts. Able to use past experience to outline the information flow/activities for a given scenario. Task analyses and data can be reusable between missions/systems. Able to identify increased workload, and task conflicts.	PCT-based HGA addresses many of the deficiencies associated with traditional HGA (Hendy et. al., 2001). PCT-based HGA provides an additional step to Hierarchical Task Analysis such that it acknowledges the need for error correction at all levels within the hierarchy. HGA can be integrated into the engineering design process. Considers all goals (highest-level to lowest-level) as possibilities to be assigned to agents, either human or machine.
Disadvantages	Provides a narrow view of the task, and should normally be used in conjunction with other task analysis methods to increase its effectiveness, and to develop a more complete understanding of human activity. Generally used to describe simple rather than complex tasks.	Extensive effort to complete a MFTA. Individuals conducting the MFTA may not be the same individuals responsible for designing the system, creating the need for a large data transfer.	Considerable time. Training and experience required to implement.
Applicability to Intelligent Adaptive Systems	Provides a model for task execution, enabling interface designers to envision the goals, tasks, subtasks, operations, and plans essential to operators' activities (Crystal & Ellington, 2004). Can be easily extended to provide system and information requirements. Information needs (both input and output) are typically deduced for the tasks. These needs, when combined with task relationship information, can provide a basis for prioritizing, clustering, filtering, or sequencing information presentation in an interface design (Miller & Vicente, 2001).	MFTA task hierarchy would need to be modified and expanded to consider intelligent agents (Chow et. at., 2006). Produces information and action requirements which could inform training and interface design, or task re-allocation to support multiple operators/systems. Able to identify high areas of workload and task conflicts, identifying where system support may be required.	Designing for control loop stability between an Operator and machine can ensure that the proper controls and displays are embedded in an interface, to ensure that perceptual errors inherent in human-machine interaction are minimized. The HGA hierarchy accounts for error correction at all levels of the goal hierarchy. The primary output from a HGA analysis is a goal structure which provides interface guidance. Output from a HGA analysis will identify cognitive and perceptual information related to Output Interfaces and Input Interfaces.

Tables 10, 11 and 12: Summary of analysis methodologies.

	Goal Directed Task Analysis	Cognitive Task Analysis	Team Cognitive Task Analysis
Advantages	Details the SA requirements relevant to attaining each goal. Identification of the SA requirements will aid evaluation and design of systems to ensure that system supports an Operator in building and maintaining a high-level of SA	CTA can boost human performance by guiding the development of tools and programs that support the cognitive processes required for a task. Able to analyze task performance in situations that involve change, uncertainty and time pressure. Aid experts in articulating knowledge that is generally difficult to verbalize.	The output to Team CTA provides input to team design, team performance measurement, and team training. The output to Team CTA provides results that can act as input to other analysis methods. Useful for analysis complex multi-person judgements and decision-making. Aids the design of systems and interfaces that are used for teams.
Disadvantages	Comprehensive method taking extensive time to complete; Requires several sessions with subject matter experts (SME) to define the domain. Degree of subjectivity during the SME sessions.	CTA encompasses a collection of diverse approaches with very little connection or cohesiveness. CTA cannot be viewed as a standalone analysis. It needs to be an iterative process that learns from subsequent design activities.	Extensive time and expertise required. Common challenges are apparent when conducting group interviews. Little research regarding the application of Team CTA techniques. Application of a method of analysis designed for individuals to teams is not sufficient for true understanding of how a team works.
Applicability to Intelligent Adaptive Systems	Identifying what information an Operator needs to know, providing guidance for designing a meaningful interface design. Identifying functional grouping of information. Guiding the relationship between information and decisions to support goals. Identifying critical cues required to direct shifts in task priority.	CTA can boost human performance by guiding the development of tools and programs that support the cognitive processes required for a task. CTA must work within a system development process and support critical system design issues.	Views a team as an intelligent entity, and attempt to identify the cognitive processes required by team dependent tasks. Captures the cognitive processes of a team, and focuses on the way a team coordinates the understanding of the different members and synthesizes the task elements. Used to identify information, cues, and strategies required to make key decisions.

	Applied Cognitive Task Analysis	Cognitive Work Analysis	Applied Cognitive Work Analysis
Advantages	ACTA techniques are easy to use, flexible, and provide clear output. Identifies where a system's design must support human problem-solving and decision-making by assessing complex tasks that require a high degree of cognitive skill.	Results from CWA can be transferred directly to design requirements. Accounts for the role of the workers in complex systems. Also focuses on analysing the environment. The model provides traceability of decision making in a organisational structure. The model provides a link between the abstract functions in the higher hierarchy level and the plans/courses of action in the lower hierarchy level.	Identification of high-level domain goals (FAN) allows for development of novel visualization of the non-physical abstractions, provide more effective support of individual and collaborative decision making and planning. Organizing operator cognitive requirements around nodes in FAN, rather than organizing requirements around predefined task sequences (as in traditional approaches to task analysis), results in decision-support systems that have a decision-centered perspective, and are thus able to support performance in unanticipated situations as well as expected situations. Providing a step-by-step set of linked processes from cognitive analysis to design insures traceability of design elements to cognitive requirements they are intended to support. Design artefacts capture the results at each stage of the process. Application of this method leads to the development of a prototype.
Disadvantages	Although ACTA elicits important cognitive information, there is a trade-off when using a streamlined approach; the more streamlined and proceduralized CTA techniques become, the less powerful they are (Militello & Hutton, 1998). ACTA techniques may gather less comprehensive information than more systematic techniques.	Complex method requiring considerable expertise. Extensive time required to learn and use. Difficult to define and map the system on all five stages. Little practical difference between CWA and ACWA. Many times, CWA will only be applied using the first few stages, which resembles more of the ACWA process. CWA is more of an academic endeavour with more attention being placed on completing the process as opposed to using the analysis to	Complex method requiring training and experience Little practical difference between CWA and ACWA. ACWA has few practitioners, and lacks support tools.

		drive design and develop design concepts.	
Applicability to Intelligent Adaptive Systems	ACTA provides data that translates more directly into applied products such as improved training scenarios or interface recommendations. Allows systems designers to elicit and represent critical cognitive components of skilled task performance, and the means to transform these data into design recommendations. ACTA techniques were developed to elicit critical cognitive task components from Subject Matter Experts.	Identifies the constraints on information seeking, including the individual resources and the external environment. CWA investigates the information behaviour in context, therefore the results are valid for the design of information systems in the context investigated, rather then for the design of general information systems (Fidel & Pejtersen (n.d.). The framework facilitates an in-depth examination of the various dimensions of a context. A study of a particular context is, therefore, a multi-disciplinary examination with the purpose of understanding the interaction between people and information in the work context (Fidel, R. & Pejtersen, A. (n.d.). Provides a structure of human-information interaction analysis, rather than subscribing to specific theories or models (Fidel & Pejtersen (n.d.). Workers will implement lower levels of cognitive control more quickly, effectively, and effortlessly than higher levels of cognitive control. Interfaces should therefore present information that allows workers to rely on lower levels of cognitive control (Naiker, 2006)	Knowledge acquisition is tightly coupled to modeling of the work domain as well as the development of Decision Support Systems.' The approach is able to yield novel decision support concepts that were finely tuned to the cognitive work requirements of the domain. Critical decisions as well as the information required to support the decisions are overlaid on the nodes in the FAN. The application of this method provides a "decision centred" design specification.

Tables 13 and 14: Summary of design methodologies.

	Joint Application Design / Development	US Department of Defence Architectural Framework
Advantages	Effective technique for building operator commitment to the success of application systems through active participation in the analysis of requirements and the specification of the system design. Extensive operator involvement in systems requirements definition. JAD results can be used as input to other methods (e.g., knowledge elicitation technique). Workshops facilitate a common understanding amongst designers, operators and stakeholders. Decisions (and reasoning for decisions) are well documented.	Comprehensive architecture that provides extensive details of a system's components. Able to identify multiple players within a system, which can result in a systems of systems analysis. Can support the System Engineering approach to provide a more rigorous method for generating requirements. The information gathered to develop the DoDAF frameworks can be used as valuable data input for Human Factors and Cognitive Engineering analysis techniques such as: Mission, Function, & Task Analysis, Hierarchical Goal Structure; and Cognitive Work Analysis.
Disadvantages	Extensive preparation. Focuses on system objectives and process outcomes, as opposed to the cognitive components of the processes. Workshops can be dominated by individuals. Participants may be varied in terms of their status within the company (e.g., senior managers versus mid-level employees), impacting the amount of participation from individuals.	Describes what types of information need to be captured but it does not detail how that information should be captured. Although DoDAF documents system architectures, it does not address software architectures. Software views are sometimes needed to supplement DoDAF representations. Complex method, involving extensive cost, expertise, and time. No specific human-related views within the framework
Applicability to Intelligent Adaptive Systems	Identifies the system requirements from an operator perspective. Drives top-priority requirements and interface concepts.	Applicable across: concept design, requirements analysis, function analysis, interface development, team development, performance, workload, and training

	Explicit Models Design	Ecological Interface Design
Advantages	Supports multi-agent system development. Incorporates the concept of feedback, defining the support required between the operator and the system, allowing one agent to convey its goals, plans and knowledge to another agent.	Approach accommodates both perceptual and analytical cognitive processing. Accounting for perceptual and analytical cognitive processing facilitates optimal interaction between system and operator agents. EID was developed to ensure the safety and reliability of complex systems.
Disadvantages	Difficulty in characterizing the knowledge according to one of the five models. Difficulty in coordinating the interaction of knowledge between models	Does not address implications of automation, such as boredom and fatigue, that can result from repeated applications of rule-based and skill-based behaviours; and Does not address how to detect when Operators would become over-reliant on perceptual behaviours and fail to use knowledge-based skills in situations where they are required. Little experimental research to support EID approach.
Applicability to Intelligent Adaptive Systems	Constraints on human processing, such as attention span, should be accommodated for in the design; An intelligent system should be a partly autonomous agent; An Intelligent system should be designed to incorporate explicit active models of tasks, operators, the system, and the dialog with the operator; and An intelligent system should model operators in terms of their individual characteristics. Supports multi-agent system development; and Recognizes Operator and System roles as agents and allows for the involvement of both multiple human operators and system agents, each represented by its own Operator or System Agent Model (Edwards, 2004). External agents are recognized as also possibly supporting the goals of both human operators and system agents	Accounting for perceptual and analytical cognitive processing facilitates optimal interaction between system and operator agents, by accounting for both skill and rule based behaviours. EID specifically designed for complex systems; and Provides effective mappings between domain goals and OMI characteristics.

5 Agent-Based Design Principles

5.1 Introduction

Intelligent Adaptive Systems can be considered in the context of a human-electronic crewmember team involving collaborative and co-operative interaction between the human and the computer-based agents (see Taylor, 1997). As such, research relating to understanding and aiding human interaction in real-world systems is critical. This review will examine issues relating to this collaborative co-operative environment, such as human-agent teamwork, organisation, and interaction.

Edwards (2004) defines autonomous software agents as programmes that have the ability to sense their environment and act on the environment over time to achieve a particular goal. Agents can be *communicative* (i.e., interact with other agents or people), *adaptive / learning* (i.e., can change their behaviour based on past experience of interacting with the operator), and *mobile* (i.e., can move themselves from one machine to another). Edwards argues that agents offer number advantages for the development of IASs; particularly, agents acting intelligently and autonomously are ideally suited to attaining control of some tasks from the human operators. Edwards also describes how the development of agents can be integrated into the CommonKADS and Explicit Models Design approaches (Section 9.3.3).

5.1.1 Background

A prominent factor limiting tactical performance is the inability of operators to realise the full potential of their equipment. One aspect of this problem is that operators cannot process all the information presented to them in the limited time available. Advances in automation have aided the operator in this task. Though conventional (i.e. fixed or static) automation can reduce pilot workload, automated systems have forced pilots to act in an increasingly supervisory capacity. This has led to an increase in errors associated with monitoring control by the operator with a consequent impact on task performance. A myth about the impact of automation on human performance is that, as investment increases, less investment is needed in human expertise. In fact, increased automation creates new knowledge and skill requirements. Today, this issue is even more relevant due to more capable technology and the increased potential for automation and support at higher levels. Banbury (1997) summarises a number of problems associated with increased automation:

- *Increased monitoring load*. The automation of functions will leave the operator with fewer functions to execute, but with a more complex system to monitor; a function at which humans do not excel;
- *“Out-of-the-loop” performance problems.* Numerous studies (see section 10.1.1 for a review) have shown that the implementation of automation may make humans slower and less accurate at failure detection when they become passive as compared to active decision makers. Situation Awareness is one of the primary factors underlying out-of-the-loop performance problems; SA suffers as the operator becomes a passive decision maker;

- *Loss of skills*. In relation to the out-of-the-loop problem, a loss of skills may also result, rendering operators less able to perform functions when they resume manual control following an automation failure;
- *Over-trust (i.e. complacency) and under-trust (i.e., scepticism)*. Operators may possess either too much trust in automated systems, leading to a false sense of complacency and lack of proper monitoring, or a complete lack of trust, characterised by complete disuse of the system, even when it might be beneficial. Both result in sub-optimal performance, and the latter also creates an increase in workload.
- *Increased system complexit*y. The addition of automation tends to increase system complexity; not only is the initial system present, but the new system then automates a function, which means more components to monitor and more systems for the operator to understand. Furthermore, there is an increased probability of system failure associated with the increased number of systems, adding to the complexity of the operator's role.

The potential for automation-induced error has raised concerns over possible losses in operator SA and experiencing difficulty in returning to active control when necessary. Reducing pilot workload, while maintaining SA, can only be accomplished by adopting a human-centred, as opposed to technology-centred, approach to cockpit automation. Operators should, therefore, play a more active role in the control loop; the reductions in operator workload are manifest from the system improving, rather than replacing, the operator's decision making ability.

Reference:

Parasuraman, R. and Riley, V. (1997). Humans and automation: Use, misuse, disuse and abuse. Human Factors, 39(2), 230-253.

Overview:

Various theories and empirical studies pertaining to human use, misuse, disuse and abuse of automation are reviewed in this paper. The results of this review led to recommendations for the improvement of system design and training methods and policies and procedures involving automation use.

The author defines automation and the role that humans play in automated systems. A review of incidents and accidents with automated systems shows that there are problems with automation related to automation usage decisions and a misuse of when and why to use it.
The authors define the terms misuse, disuses and abuse of automation:

- Misuse: an over-reliance on automation;
- Disuse: underutilization of automation; and,
- Abuse inappropriate application of automation.

These issues can be influenced by extraneous factors, which in turn influence operator performance. The factors that can influence the use of automation include:

- Individual attitudes towards automation;
- While unclear, there is some evidence that task load can influence automation;
- Cognitive overhead can influence operators not to use automation if the operator does not

believe that its initiation can overcome the cognitive overhead (takes more work to implement than if they did it themselves);
- Reliability and operator trust; and,
- Self-confidence, risk, individual differences can also influence automation use either directly or indirectly as a moderator.

The authors outline factors that can influence the misuse of automation:

- Over-reliance on automation can lead to monitoring errors;
- Operator decision biases such as using decision heuristics may lead to monitoring failures, commission errors, and over-reliance on automation; and,
- Automation reliability and consistency can lead to over-reliance.

The authors outline some factors that may influence the disuse of automation:

- Mistrust of the automation may lead operators to disable or ignore (e.g., alerts) automation.

The authors outline some factors that may influence the abuse of automation:

- Management practices or corporate policies may prevent the use of automation;
- Indiscriminate application of automation by using a technology-centered approach without considering the resulting roles and responsibilities of the operator; and,
- The automation is granted too high a level of authority without appropriate feedback, and removing the operator from the decision making process of when and how to use the automation may lead to complacency, decreased trust, and monitoring performance.

<u>Conclusions for IASs:</u>

- Results from reviewing the factors influencing automation use suggest that individual operators should be made aware of their biases (due to individual differences) on automation use. Other recommendations are:
    - Better operator knowledge of how automation works;
    - Implementation of policies and procedures that highlight the importance of when and where to use automation;
    - Teach operators to make rational automation use decisions; and,
    - Make automation easy and efficient to use.
- Results from reviewing the factors influencing automation misuse suggests that making automation state indicators and adaptive task allocation to enhance operator involvement, and using display techniques may enhance operator monitoring performance. Other recommendations are:
    - System designers, regulators and operators should be taught to recognize automation over-reliance and its consequences;
    - Let operators use automation cues as heuristics for making decisions; and,
    - Provide appropriate and accurate feedback of automation state.
- Results from reviewing factors influencing automation disuse suggests that designers of alerting systems must account for the decision threshold (false alarms versus sensitive alarms), and the base rate of the dangerous condition to enhance operator trust and use of automation.
- Designers of alerting systems should consider using alarms that show the “likelihood” of a dangerous situation rather than having the operator rely on the automation as the final

authority (essentially putting the human in the loop for decision making).

- Results from reviewing the factors influencing automation abuse suggests the following recommendations:
    - Define an operator's role based on the operator's responsibilities and capabilities, and not because the technology is simply available.
    - Design the system to encourage active operator involvement.

Reference:

Manzey, D., Bahner, J.E., and Hueper, A.D. (2006). Misuse of automated aids in process control: complacency, automation bias and possible training interventions. Proceedings of the 50th Human Factors and Ergonomics Society

Overview:

The paper outlines a study to investigate complacency effects when operators interact with an automated aid in a process control simulation task. Possible performance consequences (i.e. automation bias in terms of commission errors, and impairments of return-to-manual-performance in case of automation breakdown) are also examined. The effect of a specific training intervention to reduce complacency by exposing participants intentionally to automation failures is also investigated.

The results provide clear evidence for complacency effects due to insufficient verification of recommendations provided by the automated aid.

Conclusions for IASs:

1. The authors suggest that confronting operators with rare automation failures during training may be a suitable way to reduce complacency, yet may not be sufficient to prevent complacency effects completely.
2. The risk of commission error was associated with comparatively high levels of complacency only; usually less information needs to be sampled to falsify an automatically generated diagnosis than to verify it completely.

5.2 General Design Principles

A number of researchers have developed sets of principles of adaptive systems design. These principles can be classified into those concerned with adaptation and those with interaction. Both sets of principles are summarised as follows:

5.2.1 Principles of Adaptation

- The requirement for aiding is not only dependent on impending tasks, but is also contingent on recently completed tasks (Morris and Rouse, 1986);

- If operator modelling is used to determine the intervention of the aid, the success of this approach will depend upon the amount of structure in the task. Tasks that require high levels of judgement by the operator may not be suitable candidates for the application of this approach (Rouse, Geddes and Curry, 1987);
- If a model can provide perfect predictions of an operator's intentions and actions, there is no need to communicate adaptation explicitly, and thus the cost of explicit communication can be avoided. However, as uncertainty increases, predictions will frequently be wrong, and as a result, tasks will "slip through the cracks" or receive redundant efforts. To avoid these possibilities, increased explicit communication is required to check or calibrate a model's prediction (Morris and Rouse, 1986); and,
- If possible, the IAS should have the capability to predict the effect of individual differences on the efficiency of how cockpit tasks are conducted. Such assessments could provide assistance in deciding the most appropriate level of aiding that an operator may require in a given situation (Morris and Rouse, 1986; Lehner, Cohen, Thompson, and Laskey, 1987).

Reference:

Miller, C.A. and Dorneich, M.C. (2006). From Associate Systems to Augmented Cognition 25 Years of User Adaptation in High Criticality Systems. Poster presented at the Augmented Cognition conference, October 2006, San Francisco.

Overview:

In the 1980's, the U.S. Air Force initiated the development of a human-adaptive, information, and automation management technology known as the "Pilot's Associate".

ROLE	AGENT	AUTHORITY
ACQUIRE	💻 😐	💻 😐
ANALYZE/ PRESENT	💻	💻
DECIDE	💻	💻 😐
ACT	💻 😐	😐

What is it? PA, and all of the subsequent associate systems, consisted of an integrated suite of intelligent subsystems that were designed to share (among themselves and with the pilot) a common understanding of the mission, the current state of the world, the aircraft and the pilot. Associate systems were designed to use the shared knowledge to plan and suggest courses of action, and to adapt cockpit information displays and the behaviour of aircraft automation.

Automation of tasks: Tasks are automated only in line with the operator's goals and, whenever feasible, to be authorized by the operator. Operator control of the automation was established either during the mission, immediately prior to execution of automation, or pre-mission, in a pre-authorization mode.

Lessons Learned from PA efforts: Associate systems were and are the predecessors of augmented cognition (AugCog) technologies. While there are many similarities between PA and AugCog systems, there are also some many differences:

- Associate systems leave the pilot "in charge" which is extremely important in high criticality domains. To increase the chance of operator acceptance, it is important to consider that the operator should be kept in the loop. The authors claim that if the pilot is responsible for the actions of the aircraft, then the pilot must be the final authority of the aircraft's actions.

- All components (e.g., sensors, information fusion technologies, and interfaces) should be co-developed and evaluated in concert.
- A task-based framework was an effective way to coordinate a variety of processes (or subsystems) and minimize the costs of revising or extending them.
- Personification (or customization) is out of place in high criticality domains (and possibly other domains, as HCI).
- OMI design proved to be an important component of the associate system. It was often found that the OMI will highlight anything that is wrong with any module, and errors in the design of the OMI will make all other aspects of the associate less effective.
- Adaptation of systems to individual differences and operator expectations (but not customization) can have large payoffs for fitting a system to an operator's needs and capabilities.

Conclusions for IASs:

Several "Lessons Learned" from the PA efforts were outlined in this paper, which have implications for the development of IA systems (see Lesson learned from PA efforts above):

1. *Importance of operator acceptance and, therefore, importance of keeping human "in charge".* The authors advocate migrating control to a supervisory level (where the human varies the amount and level of automation) and that the system should not rely too heavily on inferred operator state or intent. This can increase human out-of-the-loop problems.
2. *Importance of co-development and progressive testing*: Development efforts and individual technologies should be co-developed and used in collaboration, which can aid the development of an overall system. For instance, the development of neurophysiological sensors or "meters", other means of assessing operator state, and the development of methods for "augmenting" cognition through information display technologies need to be co-developed and evaluated in concert.
3. *Benefits of an explicit, integrative framework (task model).* Knowledge of the task context can help develop systems that manage task demand and increase operator performance.
4. *Operator-machine interactions.* More effective means of interactions between the operator and the system may be achieved if the designer approaches an intelligent system as a "personified agent" whose goal it is to aid the operator and to recognize that the operator might have feelings or attitudes.
5. *Importance of interface and interaction design.* A system, especially for a high criticality domain, should be designed with a system failure in mind. The authors provide some methods that can accomplish this: give the operator the ability to override and turn off the technology; allow the operator to explicitly authorize a display modification, to be notified of pending changes, to be notified of executed changes, and to rapidly return to a previous display state.
6. *Importance of learning, especially individuation.* Recording individual performance effects could serve to provide a powerful means of adapting system behaviour to the individual.

Reference:

Albery, W., and Khomenko, M.N. (2002). Differences in Pilot Automation Philosophies in the US and Russian Air Forces Ground Collision Avoidance Systems. In Proceedings of RTO Human Factors and Medicine Panel (HFM) Symposium held in Warsaw, Poland, 7-9 October 2002.

Overview:

This paper details two automated collision avoidance systems designed by the US and by Russia, and distinguishes between the roles of the human in both systems.

The US Air Force developed a Ground Collision Avoidance System (GCAS) that is automatic and requires no pilot intervention. The underlying philosophy of this system is reliability, pilot unobtrusiveness, and invisibility. Russia also developed a pilot state monitoring system that is automatic, but includes the pilot in its control loop (IKSL). The Russian system includes an onboard video camera that allows ground operators to observe the pilot during the mission.

The *Auto GCAS* solved the problem of a disabled or disoriented pilot by providing a “safety net” of a minimum altitude the aircraft can penetrate. The *IKSL* relies on the judgment of the ground controllers to interpret the signals from the on-board system and to “take over” the aircraft, if required. The Auto GCAS does not rely on any inputs from the pilot; it is aircraft state dependent. The IKSL has the pilot in the loop, and must have signals from the pilot in order to operate.

The difference in philosophies between the two systems reflects the philosophies of the air forces of the two countries. The authors suggest that the *American fighter pilots* would probably not turn on the GCAS during actual combat missions, that they are intolerant of false positives, and are uneasy about relinquishing complete control of their aircraft to the system. The *Russian approach* meanwhile, is in the creation of a “partner system” that can help and assure the pilot in dangerous and emergency situations.

Conclusions for IASs:

1. The authors conclude that implementing automation must consider cultural aspects.

2. It is recommended that fully automated systems (at all roles/stage of information processing) should not be used in complex environments, particularly when serious consequences may result from system failure.

3. Shared agent and authority of roles can be an optimal approach to help and assure operators in dangerous and emergency situations (Russian model).

Reference:

Oppermann, R., Rashev, R., & Kinshuk. (1997). Adaptability and adaptivity in learning systems. In A.Behrooz (Ed.), Knowledge Transfer Volume II. Ace, London, pp. 173

Overview:

This paper discusses the applicability of *adaptability* and *adaptivity* features to learning systems. The paper also discusses the adaptation needs of learning systems, with particular focus on *Intelligent Learning Systems* (ILS). A comparative study of office application systems was completed which have been an important research area in the field of adaptation facilitation.

Within the human-computer interaction literature, a model for levels of adaptivity has been proposed by Oppermann (1994; 1997). Adaptivity can be thought of the full range of a continuous spectrum, representing the degree of operators' control and involvement. Oppermann's spectrum of adaptivity is anchored on one end by fully adaptive interfaces, representing no operator involvement or control, and on the other end by fully adaptable interfaces, representing full operator involvement and control.

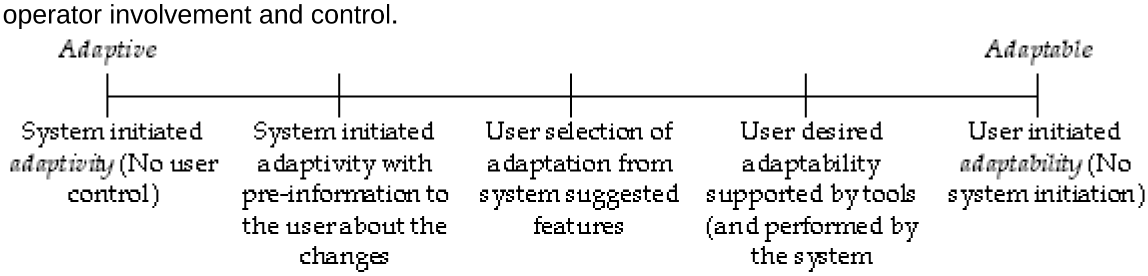


Figure 1. Spectrum of adaptation in computer systems

Conclusions for IASs:

1. To provide adequate knowledge acquisition, the system requires evaluation of the operator's behaviour without permitting the operator to modify the system's assumptions about his/her behaviour.

Reference:

Robert, S. (2006). Adaptive User Interfaces and Automation: Finding Balance between User Control and Workload, Unpublished manuscript, Department of Psychology, Carleton University, Ottawa, ON, Canada.

Overview:

Provides a good review of the benefits and costs of automatic and operator-controlled systems, and analyzes how they have and have not resolved problems of contemporary interactive systems.

To further understand this problem from a more global perspective, additional models from HCI, HF and automation domains are reviewed.

- Costs associated with automatic systems include the potential to increase workload and out-of-the-loop performance problems.
- Adaptable OMIs seem to relieve the operator from feeling “out of control” is however they can result in an increase workload and a loss in performance, since time taken away from completing tasks and directed towards customizing the interface.
- While mixed-initiative systems afford operators more control over automation and its initiation, operators still report feeling out of control. In addition, mixed-initiative interfaces typically require operators to stop work and accept or reject recommendations, with some interfaces requiring operators to then implement the change. This may potentially hinder operators who already have a large workload and are working in a complex dynamic environment.

Roberts (2006), in a comprehensive review of adaptive interfaces and automation, has proposed a framework that aims to outline the problem space of adaptive interfaces and automation, and find a balance between workload and operator control.

<u>Conclusions for IASs:</u>

1. The amount of operator control and involvement (adaptivity and automation) and the roles that humans and machines engage in or are in control over (i.e., information processing) should be considered IAS design.
2. The approach to automation and adaptation should be more flexible and dynamic rather then fixed. This suggests a more flexible system or interface that changes based on some criterion. Such changes can occur across various levels of control and roles, and should be based on operator needs that emerge from empirical testing. For example, an operator could be provided with an adaptive interface until the operator is able to understand the benefits, and then later, the operator could be given more control over certain roles, or be made completely adaptable.
3. Roberts (2006) is careful to point out that that by dynamic, it is not implied that it should be ‘flexible’ per se. This intentional dynamic flexibility will allow the operator to be kept in the loop while still allowing a relief of workload. Artificial intelligence is not allegedly ‘intelligent’ enough at the present time to flexibly attend to every need and goal of the present operator. The dynamic nature of an adaptive interface should be intentional; that is, intentional in that the way the interface changes should be tested empirically and/or through usability. In other words the adaptive interface should not rely on artificial intelligence (i.e., agents) to dynamically and flexibly adapt to an operator’s every need, but an interface that is dynamic based on pre-defined operator needs should be provided.

<u>Reference</u>:

Kaber, D.B., Wright, M.C., Prinzel, L.J., and Clamann, M.P. (2005). Adaptive automation of human-machine system information-processing functions. Human Factors, 47(4), 730-741.

<u>Overview:</u>

This paper explores the ability of human operators to interact with adaptive automation applied to various stages of a complex system's information processing, and is defined in a model of human-automation interaction. A study examined human performance (adaptation) with adaptive allocation of automation (control mode switching) at various levels of information processing (from low to high cognitive processing). The means of adaptation was based on a *user model* of operator performance on a secondary monitoring task as an indication of workload.

The following results were found:

- Participants adapted better to adaptive automation (AA) when it was applied to sensory and psychomotor functions (i.e., information acquisition and action implementation), than to AA applied to cognitive functions (i.e., information analysis and decision making).
- Adaptive automation (i.e., at all stages of information processing and the initiation of automation) was superior to complete manual control of tasks.
- In lower cognitive functions, transparency of the system was easier to maintain. It was harder to validate complex decisions that require mental simulation and calculations.
- Operator performance was best under automation under all roles, except for action implementation when compared to full manual.

<u>Conclusions for IASs:</u>

1. Study results suggest that knowledge development of a system requires sufficient training to ensure that an operator has acquired a proper mental model of the system.
2. There is a need to investigate the possibility of sensory cuing for adaptive automation (mode switching).
3. Adaptive automation may be better applied to lower (information acquisition and action implementation), rather than higher information processing (analyzing information and decision making).
4. Automated information acquisition, analysis and action implementation can help reduce workload and increase performance in ATC tasks.

<u>Reference:</u>

Schneiderman and Maes (1997). Excerpts from debates at IUI 97 (Intelligent User Interface Conference) and CHI 97

<u>Overview:</u>

This paper is an excerpt from debates at IUI 97 (Intelligent User Interface Conference) and CHI 97. Schneiderman and Mares debate direct manipulation versus intelligent agents. Schneiderman, while not against the use of intelligent agents, cautions in their implementation. Maes strongly advocates for the use of agents.

<u>The following benefits of agents are identified by Maes:</u>

- A software agent has the ability to know the individual operator's habits, preferences, and interests.
- A software agent can be proactive.
- Software agents are more long-lived. They keep running, and they can run autonomously while the operator goes about and does other things.
- Software agents can be adaptive in that they track the operator's interests as they change over time.

Conclusions for IASs:

1. Maes claims that agents can be used to help operators deal with increasingly complex and dynamic environments, such as the internet with a vast network that is continuously changing.
2. Maes claims that agents can be used to maximize operator attention and the time taken on other tasks. For instance, an agent can monitor the environment for aspects of interest rather than the operator constantly monitoring and not spending time on other tasks.
3. Maes identifies several misconceptions about agents:
    - Agents should not be used as a substitute for direct manipulation. Direct manipulation interfaces and agents can be complementary.
    - Some people believe that agents are personified or anthropomorphized, while most agents are not.
    - Another misconception is that agents rely on traditional AI techniques, like knowledge representation and inferencing. However, most agents commercially available have proven successful with large numbers of operators relying on either operator programming or on machine learning rather than traditional AI techniques.
4. Schneiderman is careful to point out that agent-operator collaboration can only be successful if the operator can understand and trust the agent. Operators must be able to turn over control of tasks to agents but operators must never feel out of control. He cautions designers against the use of anthropomorphic representations (e.g., Microsoft's paper clip) as it may interfere with predictability, reduce operator control, and may undermine the operator's responsibility. He recommends an "invisible" or transparent agent as potentially more effective.
5. Schneiderman mentions that OMIs should be predictable, so that operators trust them. He claims that direct manipulation designs can promote rapid learning, as they support rapid performance and low error rates while supporting exploratory usage in positive ways.

Reference:

Hou, M. Kobierski, R., Herdman, C. (2006). Design and Evaluation of Intelligent Adaptive Operator Interfaces for the Control of Multiple UAVs. Proceedings of the RTO Human Factors and Medicine Panel Symposium held in Biaritz, France.

Overview:

This paper reports on a multi-phase project to investigate the potential of artificial intelligence for the control of multiple UAVs. The three phases include IAI concept development, interface prototyping, and experimentation. Human-in-the-loop trials in a realistic mission scenario were conducted to examine the performance model developed by DRDC.

Several recommendations are provided for the design and implementation of IAIs. This paper has been previously described in Frameworks Section 8.4.4.

Conclusions for IASs:

1. Results suggest that operators of IAIs should be given a training period before actually using the system, particularly in life-critical, mission-critical systems.

2. A hybrid adaptive OMI based on experience with the adaptive system may increase an operator's understanding of the system and its impact; a phase dependent mix between fully automatic and operator-controlled adaptation.
3. The system should inform the operator of any interface changes. For instance, the IAI should either indicate for a few seconds where it is going, or indicate what has changed.
4. The interface should allow the operator to return to the system state that was in effect before the IAI reconfigured the display to increase the sense of operator control.
5. The design of each intelligent agent in a rapid prototype operator interface should be based on reality.
6. Intelligent agents should be made aware of the state of the world by accessing data fusion interim variables and associated probabilities. The authors suggest that this would allow the IAI to produce strategies that "play the odds".

<u>Reference:</u>

Scallen, S.F. and Hancock, P.A. (2001). Implementing Adaptive Function Allocation. The International Journal Of Aviation Psychology, 11(2), 197–221

<u>Overview:</u>

This paper details a study that examined the efficacy of adaptive allocation on operator performance and workload. Adaptive allocation was implemented in a multiple task aviation paradigm. Pilot performance was evaluated in three tasks related to tracking, system monitoring, and target identification.

<u>Conclusions for IASs:</u>

1. Adaptive function allocation (AFA) appears to improve tracking, monitoring and targeting performance, and more accurate perception of the passage of time (or increase situational awareness).
2. Implementation of adaptive allocation of automation could produce positive benefits to a wide range of pilot functions including task prioritization, mission segmenting, task initiation and cessation, risk identification, and workload management.
3. The authors suggest that it would be a mistake to consider automation as environment specific. Therefore, if adaptive automation is implemented in seemingly disparate environments, it is likely that both the physical environment and the human–machine interaction will co-evolve.
4. Performance trade-offs may hinder effective implementation of adaptive strategies.
5. Adaptive aiding could help prioritize functions (e.g., in this time-stress phase, pilots restrict their sampling of information to what they perceive as most important, but they are not always accurate).

Reference:

Hancock, P.A., Scallen, S.F., and Duley, J.A. (1995). Interface design for adaptive automation technologies. Proceedings of the 3rd international workshop on human-computer teamwork (Human-Electronic Crew: Can we trust the team?). Cambridge, UK, 27-30 September 1994.

Overview:

The paper outlines a study where the effects of differing levels of pilot involvement were examined in the context of initiating automation. The following levels of automation were investigated: complete pilot control, complete automation control, system-recommended automation, and system-invoked automation. Results indicate that system invoked automation produced less time in manual control, less time to initial automation (i.e., participants were transitioned to automation much more quickly than the other groups), and an increase in fatigue.

Conclusions for IASs

1. The authors suggest that based on their study, the strategy to initiate automation should involve a dynamic model of adaptive allocation In terms of context dependency, there could be the following allocation of tasks to the agent: complete pilot control, complete automation control, system-recommended automation, and system-invoked automation amongst varying levels of initiation.

Reference:

Findlater, L., & McGrenere, J. (2004). A comparison of static, adaptive, and adaptable menus. Proceedings of ACM CHI 2004, pp. 89-96

Overview:

A study comparing three menu conditions, static, adaptable and adaptive was performed. Each menu was implemented as a split menu but differed in the way the customization was implemented. Results indicate that the static menu was significantly faster than the adaptive menu, and the adaptable menu was found to be significantly faster than the adaptive menu. The majority of operators preferred the adaptable menu.

There are two main approaches to the personalization of interfaces to individual operators: adaptive interfaces dynamically adjust the interface in a way that is intended to support the operator (system controlled). By contrast, adaptable interfaces provide customization mechanisms but rely on the operator to use those mechanisms to do the adaptation (operator controlled).

The authors identify that there is some debate in the HCI community (and HF) as to which of the two approaches (adaptive or adaptable interfaces) is best. One side argues that easy to use predictable mechanisms should be provided to keep operators in control of the system, while the other side believes that if the right adaptive algorithm can be found, operators will be able to focus on their tasks rather than managing their tools (high argument for automative control in HF domain).

Conclusions for IASs:

1. Results suggest that easy-to-use mechanisms are not sufficient for effective customization (adaptive); examples should also be provided to operators to guide them on how to use the customization feature.
2. Operators value an interface that can be modified to suit their individual needs.
3. Providing operators with control over the adaptation of their interface can lead to better perceived performance and higher overall satisfaction (Note that this result indicates that designers have to be careful when interpreting operator feedback on system usability).

Reference:

Inagaki, T. (2006). Design of human–machine interactions in light of domain-dependence of human-centered automation Cognition, Technology and Work. 8, 161–167.

Overview:

This paper argues for multi-layered “human-centered automation” by taking into account not only enhancement of situation awareness, but also trading of authority between humans and machines.

The authors define “human-centered automation” as an approach in which operators and systems collaborate cooperatively. They also argue that automation can be domain-dependent (e.g., ‘‘human-centered automation for automobile’’ can be quite different from ‘‘human-centered automation for aviation system’’).

Refer to this article for concrete examples on how to apply human-centered automation in aviation systems and automobiles.

The authors propose a new scale of automation levels (allocation and initiation) to Sheridan’s list (1998) that includes an extra level (#6.5):
1 The computer offers no assistance; human must do it all
2 The computer offers a complete set of action alternatives, and
3 Narrows the selection down to a few, or
4 Suggests one, and
5 Executes that suggestion if the human approves, or
6 Allows the human a restricted time to veto before automatic execution, or
6.5 Executes automatically upon telling the human what it is going to do, or
7 Executes automatically, then necessarily informs humans
8 Informs him after execution only if he asks
9 Informs him after execution if it, the computer, decides to
10 The computer decides everything and acts autonomously, ignoring the human

[From Sheridan (1992), Inagaki et al. (1998), and Inagaki and Furukawa (2004)]

Conclusions for IASs:

1. To enhance awareness of system function, the interface should be designed to allow the operator to: (1) understand the rationale behind the initiation of automation; (2) recognize intention of the automation; (3) share the situation recognition with the automation,; and (4) understand the system's limitations.
2. The authors propose a new level of automation to Sheridan's list (1998) to reduce automation surprises induced by an automatic action, as well as to make the action effective in emergencies (refer to the scale presented in the above Overview).
3. The level of automation should be adapted to the situation.
4. System designers should consider the possibility of the system to initiate automation autonomously in situations where there are little resources left for the operator to give directives to the system (e.g., pilot loses consciousness).

Reference:

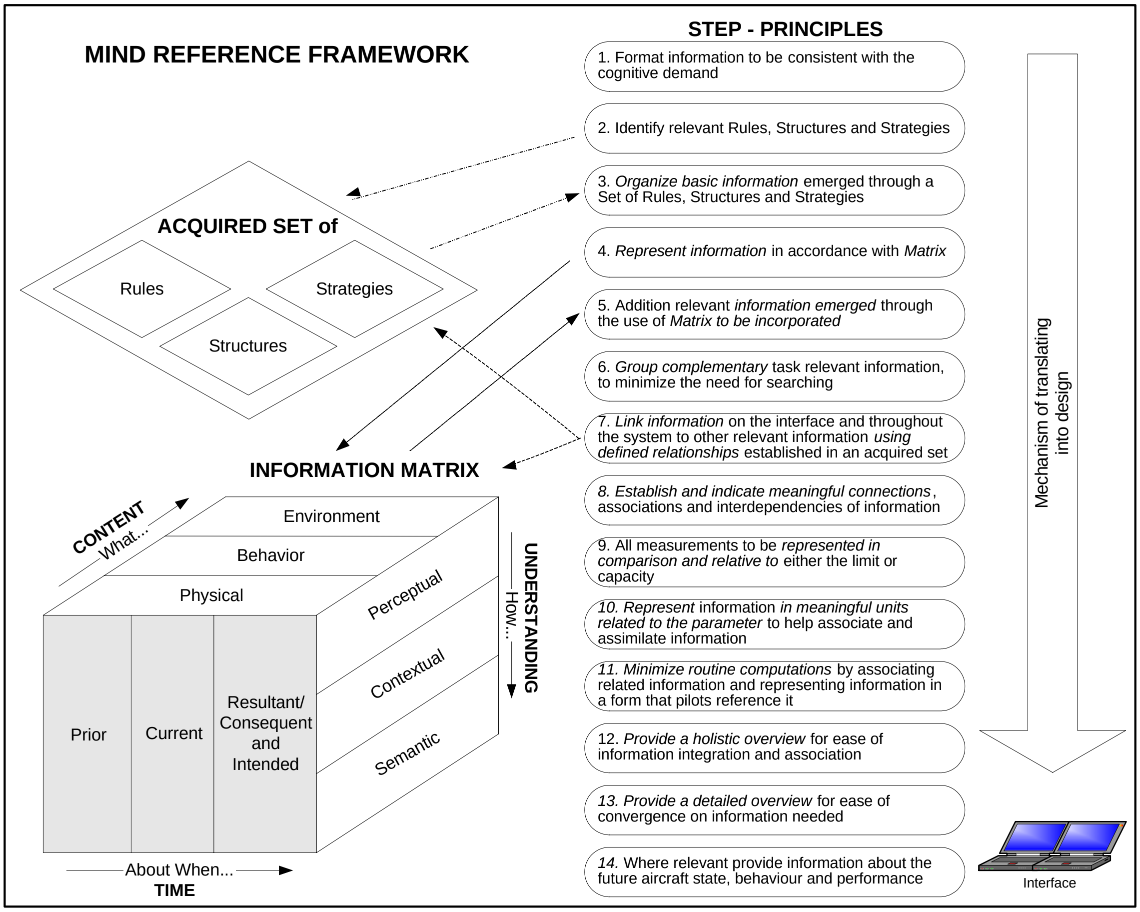
Solodilova, I., and Galster, S. (2006). Information optimization for the UMV operator interface. In Proceedings of RTO Human Factors and Medicine Panel (HFM) Symposium held in.

Overview:

This paper details the Mind Reference framework as a set of guidelines and instructions for information presentation in UMV operator interfaces. The theory is centred on how pilots in flight use a variety of Rules, Strategies and Structures to consolidate data from many sources to aid them make swift and accurate and significant decisions.

Mind Reference Framework:

The framework consists of an Information Matrix that comprises of a set of Rules, Structures, Strategies, and Relationships. The concept focuses on how to organise information throughout the information-system. It also helps to identify and explore possible presentation modes. The concept analyzes data from pilot's debrief comments and through their experience and knowledge (in part gained from the researcher observing and following parallel flight training) to uncover how pilots represent information cognitively. This data is then recorded in the matrix to be consulted as a source of guidance during interface design for organizing information and how to present that information. A set of step principles are then followed for the design of the interface (framework is presented below).



Mind Reference Framework

Please refer to the paper for details (theory and implementation) on the list of steps.

Conclusions for IASs:

1. The Mind Reference Framework provides a useful set of guidelines and instructions on how to optimally present information on IAS OMIs.

Reference:

Trouvain, B. and Wolf, H.L (2002). Design and Evaluation of a Multi-Robot Control Interface. In Proceedings of RTO Human Factors and Medicine Panel (HFM) Symposium held in Warsaw, Poland, 7-9 October 2002.

Overview:

This paper details two simulation-based multi-robot experiments that were conducted as a means to guide and support the development of a multi-robot control interface. It was determined that robot autonomy is required for a multi-robot system to be managed by a single operator. In separate trials, operators had to manage 2, 4 and 8 robots in two different environments. Participants controlled navigation and monitored inspection of robots through a UI. The two experiments examined different levels of robot autonomy on operator performance. Results from these two simulations guided their interface design process.

Conclusions for IASs:

1. Study results suggest that the OMI should present information that allows optimal performance when monitoring automation (e.g., multiple robots). The study identified that optimal performance occurred with five robots. Therefore, the layout of the UI should be based on the requirement to display status information of four to five robots simultaneously, at a maximum.
2. The impact of autonomy on an operator's performance must be viewed separately for the control and the monitoring aspect.
3. The authors believe that an operator's ability to monitor complex systems requiring autonomous components represents the actual *bottleneck in* human robot teams. That is, without sophisticated operator support supervising multi-robot systems larger than two robots, it is difficult to realize if tight monitoring is required.

Reference:

Kirlik, A., Markert, W.J., and Kossack, M. (1992). Comparison of display enhancement with intelligent decision aiding. Technical report: School of Industrial and Systems Engineering, Georgia Institute of Technology, Atlanta, GA. (NASA-CR-189895).

Overview:

Details two decision aiding strategies: display enhancement and intelligent decision aiding. Outlined is research that compares and contrasts two technologies and explains the interaction effects introduced by the different skill levels and different methods for training operators. Ecological Interface Design has been proposed as an abstraction hierarchy tool to illustrate the functional properties of a system. Research suggests that novices work more with context-free elements and rules and are not as able to identify subtle differences, are working more on a level which can be best described using rules. In contrast, experts behave more intuitively and are very context dependent.

Conclusions for IASs:

1. EID can be used as a hierarchy tool to determine the functional properties of a system.
2. A decision aid should consider the cognitive model of the decision maker.
3. An intelligent decision aid should support the level of experience and skill of the decision maker.

Reference:

Breton, R. and Bosse, E. (2002). The Cognitive Costs and Benefits of Automation. In Proceedings of RTO Human Factors and Medicine Panel (HFM) Symposium held in Warsaw, Poland, 7-9 October 2002

Overview:

This paper discusses the cognitive costs and benefits related to automation within the execution of all processes that lead to a course of action selection.

The authors identify that the largest benefits of automation relates to human workload, and the reduced demand on attentional resources. Automation was found to be accompanied by major cognitive costs, mostly related to operator execution of a task; that is, when operators must shift roles from monitor (with automation turned on) to active agent (automation turned off). Further, the passive role for the human (as monitor of automation) was found was found to potentially prevent the human from building an appropriate mental model of the situation, especially for the recovery of system failures.

The authors recommend teaching the operator to become an *effective supervisor*. The authors claim that this can be an effective balancing technique between reducing mental workload, attentional demands, the effect of fatigue and stress factors, the probability of errors, and maintaining situational awareness.

Conclusions for IASs:

1. The authors recommended investigating several factors in order to determine the level of agent role and authority the operator should have within a mission and/or task (the level of automation), and the level of workload:
    a. the attentional resources required from the human;
    b. the reduction of the stress and fatigue factors;
    c. the reduction of human error occurrence;
    d. the quality of situation understanding by the human;
    e. the human capacity to recover from system failure or the occurrence of unexpected events; and,
    f. the role of the human in the execution of the overall decision-making task.
2. The authors advocate training the human to adequately supervise the system functioning. This can offset some of the potential costs of automation by decreasing workload and enhancing situational awareness. The operator should develop an appropriate mental model of the system; training would ensure that the operator understands how the system is working, and that operators have access to the information that is considered by the automated systems in order to develop, as the situation is evolving, an adequate understanding of this situation.

Reference:

Galster, SM., Bolia, R.S. and Parasuraman, R. (2002). The Application of a Qualitative Model of Human-Interaction with Automation: Effects of Unreliable Automation on Performance. In Proceedings of RTO Human Factors and Medicine Panel (HFM) Symposium held in Warsaw, Poland, 7-9 October 2002.

Overview:

A visual search paradigm was used to examine the effects of information automation and decision-aiding automation in a target detection and processing task. Specifically, manual, information automation, and decision-aiding automation conditions were investigated.

Results indicate that there was an increase in correct responses and a reduction in search times in the information automation cue condition, regardless of the reliability of the automation. These results suggest that this is most likely due to over-reliance on the automation to give the correct guidance resulting in an “automation induced complacency effect” under the automatic condition.

Conclusions for IASs:

1. Over-reliance on automation can result in an automation induced complacency effect.
2. Automated information cueing can improve target identification performance under high target density conditions. Thus, automation cueing may be best suited for complex, dense information environments, when an operator is likely to be already near a peak level of workload.
3. Target acquisition and action implementation where there is lots of visual noise (i.e., a saturated complex visual field) is enhanced by the presence of a reliable IA cue, providing location information.

Reference:

Horvitz, E. (1999). Principles of mixed-initiative user interfaces. In Proceedings of ACM Conference on Human Factors in Computing Systems (CHI'99), pp. 155-166.

Overview:

ROLE	AGENT	AUTHORITY
ACQUIRE	💻	💻
ANALYZE/ PRESENT	💻	💻 😐
DECIDE	💻	💻
ACT	💻	💻 😐

The authors review principles for directly manipulating automation and machine learning. These principles are highlighted in terms of the program called LookOut, an automated system for scheduling and meeting management.

LookOut: Is a program that automatically populates meeting request information based on an email message text in the body and subject.

Initiation of Lookout: The system can be initiated either by the human (clicking on icon or when prompted by the system) or automatically by the system based on a goal-based user model.

Direct manipulation. The operator communicates directly with the system through an animated widget.

User model. The user model is based on a “function of an inferred probability” that the operator has a goal of performing scheduling and calendaring operations.

Confidence estimation. The level of automation (initiation and action) is based on the system’s uncertainty of the operator’s goals which is based on the user model. The authors applied probabilistic models of an operator’s goals. This is used to perform real-time inferences about the probability of alternate feasible goals by monitoring the current program context, and the operator's sequence of actions and choice of words used in a query. Bayesian network models were partially used to for a base for the confidence estimation algorithms.

Displaying automation uncertainty. The level of uncertainty about the operator's goals is displayed to the operator via visual indicators. At high levels of certainty, a character appears and indicates that it has readied a calendar view to show the operator or has created a tentative appointment before displaying the results. At lower levels of confidence, LookOut inquires about the operator's interest in either seeing the calendar or scheduling an appointment, depending on the system's analysis of the message being viewed.

Automated tasks. The decision of initiating automation is based on whether an agent believes it will have greater expected value than inaction for the operator, taking into consideration the costs, benefits and uncertainties in the operator's goals. Refer to the paper for implementation details.

Timing of prompting the initiation of automation. Automation and alerts of initiating automation is based on models of attention that consider the temporal pattern of an operator's focus of attention (timing model).

Machine learning. The system is designed to continue to learn from operators through caching operator behaviour with the system and by the operator specifying a policy for continual learning (e.g., set system to cache behaviour at particular times).

The authors recommend considering several critical factors when implementing integration of automated services with direct manipulation interfaces, as discussed below.

Conclusions for IASs:

1. *Uncertainty about an operator's goals can provide good input for inferring about an operator's intentions to perform an operation*. Computers are often uncertain about the goals and the current focus of attention of an operator. In many cases, systems can benefit by employing machinery for inferring the uncertainty about an operator's intentions and focus.
2. *Considering the status of an operator's attention in the timing of services*. Systems (or agents) could use models of attention and consider the costs and benefits of deferring action to a time when the automation will be less distracting to the operator.
3. *Context-dependent automation*. Automated functions should be applied in a context-relevant manner based on uncertainty in an operator's goals and attention.
4. *The system should resolve uncertainties through a dialog with the operator*. If a system is uncertain about an operator's intentions, it should be able to engage in a dialog with the operator, considering the costs of potentially bothering an operator needlessly.
5. *Direct invocation and termination of automation should be provided*. Efficient means should be provided which operators can directly invoke or terminate the automated services.
6. *Operators should have an efficient means to modify automation behavior*. Agents should be designed so that operators can complete or refine an analysis provided by an agent.
7. *Agent-operator interaction should employ socially appropriate behaviors*. An agent should be designed to behave in a way that matches social expectations.
8. *Recent operator interactions with the system should be saved*. Systems should maintain a memory of recent interactions with operators and provide mechanisms that allow operators to make references to objects and services included in "shared" short-term experiences.
9. *Learning by observing operator behavior*. Systems should be designed so that they continue to learn about an operator's goals and needs

Reference:

Dzindolet, M.T., Beck, H.P., Pierce, L.G., and Dawe, L.A. (2001). A framework of automation use. Army Research Laboratory Technical Report ARL-TR-2412/.

Overview:

This paper discusses how future decision support can be improved by understanding the causes of successes and failures of past decision support systems. The purpose of this report was to present a general framework to understand an operator's decision to allocate tasks to automation.

Two studies (Dzindolet et al., to be published; Dzindolet et al., 1999) were conducted to examine the role of automation bias in automation disuse and misuse. Results indicated that:

- When automation bias played a role in the decision to rely on automation, misuse occurred more than disuse.
- When the automation bias was eliminated (this was achieved by providing automated decisions only after operators recorded their decision), disuse (not misuse) was involved in subsequent task allocation decisions.

Conclusions for IASs:

- The framework of automation use presented in Dzindolet et al., (2001) framework of automation use (2001) predicts that cognitive, motivational and social processes work together to cause misuse, disuse, and appropriate automation use, and may be useful in reducing automation misuse and disuse. Please refer to the article for a detailed description of framework.
- According to the general framework, disuse appears to be a greater problem than misuse. For instance, disuse can be reduced by providing operators with multiple forms of feedback of the system's performance.
- The authors stress that automation bias should be controlled. One way to achieve this is to provide operators with the systems' decision support only after the human operator has provided a decision.

Reference:

Allen, N. and Kessel, T. (2002). The Roles of Human Operator and Machine in Decision Aid Strategies for Target Detection. In Proceedings of RTO Human Factors and Medicine Panel (HFM) Symposium held in Warsaw, Poland, 7-9 October 2002.

Overview:

The authors advocate for a balanced approach to authority over adaptation. Authorship should be matched to the abilities of the agent, operator or system. For instance, giving the system too much or too little responsibility can make it ineffective, either jeopardizing the mission or by making it an annoyance. Elementary detection theory is used to diagnose conventional detection aids.

Conclusions for IASs:

The authors recommend the following top-down strategies for system design:

1. The system must adhere to a principle of balance between the responsibilities and abilities for each detector, operator and system alike.
2. A good design strategy is to include operators in the entire development cycle, whom can be consulted to confirm the choice of a given strategy and ensure that their own responsibilities are commensurate with their abilities.
3. The design strategies in this paper can be referred to for the development of target detection systems.

Reference:

Fernall, A.P. (1997). Decision support solutions: Analysis of reasons for past successes and failures. DRA Technical Report DRA/LS3/19K2.13/DOC.3/96/3/.

Overview:

This paper discusses how future decision support can be improved by understanding the causes of successes and failures in past decision support systems. Both the design and assessment processes were reviewed, as they were both determined to be a fundamental factor in the success/failure of a support system.

Conclusions for IASs:

1. The authors found that a comprehensive cognitive task analysis can guide the development of a task-relevant decision aid, and increase the depth, breadth and focus of the system.
2. The authors report that there is often a lack of appreciation of the effects of introducing new technology. There are several misconceptions about introducing new technology including that it will improve decision making, that operators know what they want, and that introduction of the aid will lead to reduced training needs.
3. High quality HCI is often lacking in the design and implementation of many systems.
4. The authors claim that project assumptions are often not questions, and can result in serious implications:
    a. Critical requirements may be missed.
    b. A danger that functions that are easy to automate will start to dominate those that are not.
5. The authors found that the traditional design approach for developing military computer

systems is fundamentally unsuited to the design of effective decision aids.

Reference:

Lock, Z., Macklin, C., and Thompson, D. (2004). Personalized Briefing Agents: Phase II Technical Report QINETIQ/KI/CIS/TR041645/1.0

Overview:

A Personailzed Briefing Agent (PBA) system was developed and designed to interact with military officers and provide them with updated information on the status of the battle, when required, in a manner suited to their individual requirements (PBA is an information management decision making aid. The authors discuss the application of information processing and user modeling as a means of controlling information overload, and also to increase the quality of decision making. In particular, it discusses a novel user modeling method to design a system that provides context-dependent information automatically.

Novel User Modelling: Information about operators is acquired and represented so that it can be used to automatically adapt the information presented to the operator (what the authors refer to a personalizing the computer system). A multi-component user modeling approach is used to apply adaptation. Section 3.6 details these component models. Details of these models are out of the scope of this review.

Conclusions for IASs:

1. A *multi-component* rather than a *single-component* approach to user modelling is used to overcome the limitations of the single approach. In a single approach, difficulties in applying automation adaptation can arise where certain operator information requirements change over time and others stay the same (e.g., a military decision maker that changes roles within a team).
2. *Multi-component approach:* Each information requirement is associated with a particular operator perspective, such as an operator's team membership, assumed role, or current operation. Each perspective has a set of requirements and is equivalent to a single-component user model. An overall user model will then consist of a set of components. Each of these components has an associated weight, which indicates the contribution a component makes to overall relevance to the operator.
3. When a perspective changes, the corresponding component can be replaced with another that is more appropriate to the new situation. All other components, unaffected by the perspective change, remain in the overall user model.

Reference:

Hilburn, B.G. (2002). Evaluating Human Interaction with Advanced Air Traffic Management Automation. In Proceedings of RTO Human Factors and Medicine Panel (HFM) Symposium held in Warsaw, Poland, 7-9 October 2002.

Overview:

This paper summarizes the results of two studies. The first study examined air traffic controllers' attitudes toward possible new forms of automation. In the second study, a series of human-in-the-loop simulations were conducted to evaluate the potential benefits of advanced Air Traffic Management (ATM) automation on human-machine system performance.

Conclusions for IASs:

1. Results suggest that operator acceptance is heavily dependent not only on perceived reliability of the new system, but also on the nature of the reliability (e.g. is the system prone to false alarms? misses?), and on the costs involved with verifying an automated system's functioning, as compared to the relative costs of a miss/false alarm.
2. *Ensure a proper mental model of the system*. Knowing what information the system is using (and not using), and how the system can be expected to behave in various situations is critical for the development of operator trust in an automated "partner."

Reference:

Manzey, D., Bahner, J.E., and Hueper, A.D. (2006). Misuse of automated aids in process control: complacency, automation bias and possible training interventions. Proceedings of the 50th Human Factors and Ergonomics Society

Overview:

The paper outlines a study to investigate complacency effects when operators interact with an automated aid in a process control simulation task. Possible performance consequences (i.e. automation bias in terms of commission errors, and impairments of return-to-manual-performance in case of automation breakdown) are also examined. The effect of a specific training intervention to reduce complacency by exposing participants intentionally to automation failures is also investigated.

The results provide clear evidence for complacency effects due to insufficient verification of recommendations provided by the automated aid.

Conclusions for IASs:

1. The authors suggest that confronting operators with rare automation failures during training may be a suitable way to reduce complacency, yet may not be sufficient to prevent complacency effects completely.

2. The risk of commission error was associated with comparatively high levels of complacency only; usually less information needs to be sampled to falsify an automatically generated diagnosis than to verify it completely.

Reference:

Bennett, Cress, Hettinger, Stautberg, and Haas (2001). A Theoretical Analysis and Preliminary Investigation of Dynamically Adaptive Interfaces. *The International Journal of Aviation Psychology, 11*(2), 169–195.

Overview:

A study to examine the effects of 2 different adaptive OMIs (candidate and dynamic adaptive interface) on routing behaviour was performed in a simulated flight task. Non traditional controls (a force reflecting stick) and displays (a configurable flight director) were developed to support task performance in real time. Results found that the candidate and adaptive conditions led to significant performance advantages to operator performance compared to the standard interface. There were no significant differences found in performance between the candidate and adaptive interfaces.

The authors describe *a dynamically adaptive interface (DAI)* as a computer interface that changes the display or control characteristics of a system (or both) in real time. An *adaptive interface* in this study is referred to as an interface that allows an individual to modify the characteristics of an interface, but not in real time. There are three major categories in which adaptations in the DAI can be triggered: changes in system state, human performance models, and on-line assessment.

Conclusions for IASs:

1. The candidate and adaptive conditions led to significant performance advantages to operator performance compared to the standard interface. There were no significant differences found in performance between the candidate and adaptive interfaces.
2. The authors suggest that operators should have a well-formed mental model of the system (i.e., the system should be transparent to the operator).
3. The authors outline that one fundamental challenge in designing effective DAIs is to demonstrate that the dynamic changes in display or control information do not interfere with either the development or the execution of skilled behavior.

Reference:

Kirschenbaum, S.S. (2002). Uncertainty and Automation. In Proceedings of RTO Human Factors and Medicine Panel (HFM) Symposium held in Warsaw, Poland, 7-9 October 2002.

Overview:

This paper explores a range of issues related to uncertainty and automation and suggests methods to mitigating the effects of uncertainty associated with automation.

The authors report that uncertainty can occur in any situation in which the operator does have a well-established mental representation (or mental model) of the "world", and in this case, the system. Difference between experts and novices are explored. The authors report that experts are more likely to be aware that there is uncertainty in most situations. This can lead to not trusting the system (e.g., a generated answer). *The Representation Match Hypothesis* can be used to guide the display of uncertainty to alleviate these problems. It states that processing of uncertainty will be most effective (least errors, least time) when the representations of uncertainty match the representations required for problem solving.

Conclusions for IASs:

1. Adaptive automation requires the system to be transparent so that the operator and the system can function as a team. When automation behaves in an unexpected manner, operators tend to attribute it to a breakdown in functioning (hardware or software), and reject all subsequent output.
2. The Representation Match Hypothesis can guide the display of uncertainty by matching the representations required for problem solving.

Reference:

Taylor, R.M. (2002). Capability, Cognition and Autonomy. In Proceedings of RTO Human Factors and Medicine Panel (HFM) Symposium held in Warsaw, Poland, 7-9 October 2002.

Overview:

This paper is a review of various frameworks related to military capability, cognition and automation, and their relation to the role of the operator within a system. Only cognition and automation will be reported.

Cognition Frameworks: These frameworks are useful for understanding what role operators play in advanced automated systems. Simple perceive-decide-act, and the air combat-based OODA loop (observe, orient, decide, act) frameworks are recommended for function allocation to an agent (operator or a system). The author argues for an alternative class of frameworks which include "situated cognition", "naturalistic decision-making", and "cognition in the wild". These frameworks consider cognition in context and natural situations. This approach recognizes that operator performance is constrained by the conditions under which it takes place, and focuses on the variety of human performance and what cognition does, rather than what cognition is, and the internal mechanisms for achieving it.

Automation Frameworks: The author describes automation as a means of replacing skill-based behaviour (well-defined, highly structured domain), replacing and supporting some rule-based behaviour, and as supporting some knowledge-based behaviour (ill-defined, unstructured domain).

Conclusions for IASs:

1. Analysing, identifying, and allocating functions is an essential early step in HF engineering. The author reports however that standardizations (e.g., STANAG 3994) are limited to simple function analysis, rather than defining the allocation of functions.
2. The author argues for the use of frameworks that consider cognition in context and natural situations. This approach recognizes that operator performance is constrained by the conditions under which it takes place, and focuses on the variety of human performance and what cognition does, rather than what cognition is, and the internal mechanisms for achieving it.
3. The authors point to a central problem in adaptive automation which is related to the determining whether and when transfers of control to the operator should occur. One technique proposes that the transfer should occur when the expected utility of transfer is greater than that of retaining the decision-making. Another option is in highly uncertain situations where the agent should relinquish and transfer control to the operator.

Reference:

Goossens, A.A., van Ginkel, H.T.A., Theunissen, E., de Vries, M.F.L., Koeners, G.J.M., Roefs, F.D. (2006) Exploring autonomy and authority issues with respect to conflict prediction and resolution. In Proceedings of RTO Human Factors and Medicine Panel (HFM) Symposium held in Biaritz, France.

Overview:

This paper describes two experiments that were conducted to explore the level of authority (LoA) influence on operator Situational Awareness and performance within a ground control station simulation for UAVs

Experiment 1 was conducted to compare the influence of three different LoAs on several different measures of performance and SA. None of these measures yielded significant differences between the LoA conditions. Interestingly, participants often did not have good enough SA to decide whether or not it was necessary to intervene, and if so, exactly what action they should undertake. In order to better support participants' SA, the authors re-designed the system to allow the participants to intervene timely (i.e., before the system intervenes) and correctly.

In the second experiment, only two different LoAs were compared, removing the highest LoA from consideration. The results of this experiment are very consistent with the first. Again, significant differences were not found between the LoA on any of the measures. Participants scored well on the questionnaire concerning their knowledge and understanding of the situation, in both LoA conditions.

Conclusions for IASs:

1. In this instance, LoA did not impact Situational Awareness.

5.2.1.1 Adaptation Cycles

Adaptation cycles are defined as the frequency with which automation is turned on/off over a period of time. There is a continuum of short to long cycles of adaptive automation, and what constitutes short or long cycles is dependent of the particular task being performed.

Allocation from the human to the system for brief time periods could produce a potentially uncontrollable oscillation of manual and automated control. These conditions are referred to as *automation cycling*, which is measured as the frequency of automation change over a specific time period. If uncontrolled, the oscillation could prove particularly detrimental to overall performance. Particularly, short episodes of automation may also prove so detrimental that the operator may simply shut the system off. Hence, the failure to understand operator response to short episodes of automation might obviate the fundamental purpose of intelligent adaptive systems.

- Excessively long or excessively short adaptation cycles can limit the effectiveness of IASs in enhancing operator performance (Hilburn et al., 1993);
- Occasional brief reversions to manual control can counter some monitoring inefficiency typically associated with long cycle automation (Hilburn et al., 1993);
- Supervision of dynamic tasks is significantly worse than the supervision of more stable tasks (Parasuraman et al., 1996); and,
- Detection of automation failures is substantially degraded in systems with static automation in which the allocation of tasks between operator and system remains fixed over time, approximately 20 minutes (Parasuraman et al., 1996).

5.2.1.2 Dynamic (Learning) Adaptation

The dynamics and capabilities of an IAS could also change over time, as the system becomes more familiar with the operator (e.g., interaction style, commonly used tasks, etc.). Section 10.2.1.2 describes a variety of studies relating to the dynamic (i.e., learning) aspects of IASs.

Reference:

Wolfman, S.A., Lau Pedro Domingos, T. and Weld, D.S. (2001). Mixed Initiative Interfaces for Learning Tasks: SMARTedit Talks Back. In proceedings of IUI’01, January 14-17, 2001, Santa Fe, New Mexico, USA.

Overview:

An interface for machine learning is proposed. The paper describes a variety of interaction modes that enhance the learning process and presents a decision-theoretic framework, called DIAManD, for choosing the best interaction.

The authors propose that machine learning systems should closely resemble human teacher-student relationships and follow the example of the proactive yet considerate student. For instance, the system should ask questions, propose examples and solutions, and relate its level of knowledge when appropriate to make the interaction more effective.

DIAManD is a system for selecting among various interaction modes using a multi-attribute utility function. The interaction modes provide a variety of methods for an operator to interact with the system. The system selects from a set of interaction modes the mode it judges most appropriate based on the attribute vectors. The best of these modes is presented to the operator and controls the next stage of discourse, updating the state of the learner. The modes are then rescored based on the new state of the learner.

<u>Conclusions for IASs:</u>

1. The operator of a system should be able to override the system's choice of interaction mode and choose a mode that he/she prefers.
2. An attribute set must reflect the balance between operator effort and the value to the task and system.
3. The authors recommend five appropriate but general attributes, each of which should be viable for most learning system and interaction library combinations. The attributes (operator input, level of continuity, and probability of correction) focus on operator effort and represent the physical and mental effort required from an operator. The attributes (task progress and value to the system) focus on the achievement of an operator's objective. These measures reflect an operator’s typical objective of a machine learning system, which is: complete the task by refining the hypothesis of the learning system until it correctly describes the data.

<u>Reference</u>:

Parush, A. and Auerbach (forthcoming). Adaptive User Interfaces: Examination of Adaptation Costs in User Performance. To be presented at the First International Conference on Augmented Cognition (part of Human Computer Interaction International 2005), Las Vegas, Nevada, US, July 22-27, 2005

<u>Overview:</u>

Adaptive and mixed-initiative interfaces were compared in a simulated web-based help desk. The content of the simulation included requests from customers.

Methodology: The interface could change in the way requests were displayed and the way the requests were handled in terms of priority. The amount of incoming requests (task load) was the trigger for adapting the interface from form-based (designed for low task load) to list-based (designed for high task load). The adaptive interface changed from list to form automatically, and vice versa, when a critical number of requests were reached. The adaptation was based on the amount of operator workload. The mixed-initiative interface changed from list to form based, and vice versa, only after the operator had read and accepted a recommendation to do so. The two control groups received either a static form or static list based interface.

Results: Findings indicated that participants in the mixed-initiative interface group chose to ignore the recommendations even though it came with a cost of poor performance, perhaps to avoid extra workload. This study suggests that a mixed-initiative OMI is not always the best solution, particularly for situations where high workload is involved. The operators of this simulation were expected to increase their already high workload by having to first decide whether or not to switch the interface type, and secondly to implement the action chosen. This manual implementation could have served as an extra task and hence increased workload. Operators did, however, quickly learn to work with the adaptive interface which decreased the potential performance cost associated with the adaptation (e.g., increased workload and decreased task performance).

It was concluded that there is a need to influence an operator's choice of interaction strategy. They recommend making the operator realize the longer-term implications of the adaptive interface and then introduce them into the choice situation. In order to achieve that, operators may be given at the initial phase of working with the system, a fully automatic adaptation system to help them learn the longer-term potential benefits of interact with an adaptive interface. Once operators are at the point of having a good understanding of the adaptation and its impacts, then operator-controlled adaptation can be introduced.

<u>Conclusions for IASs:</u>

1. Operators of systems with adaptive interfaces should be given a training period before actually using the system, particularly in life-critical, mission-critical systems. That is, operators should only use the "real system" once they achieve a performance level that minimizes or eliminates potential costs of adaptation.
2. There is a critical need for operators to understand and experience the potential benefits of adaptation.
3. A hybrid adaptive OMI based on experience with the adaptive system is suggested to increase an operator's understanding of the system and its impact: a phase dependent mix between fully automatic and operator-controlled adaptation.

<u>Reference:</u>

Yoo, J., Gervasio, M., and Langley, P. (2003). An adaptive stock tracker for personalized trading advice. Proceedings of the International Conference on Intelligent User Interfaces, pp. 197

<u>Overview:</u>

The Stock Trader system investigated operator performance. The system addresses information overload by tailoring recommendations based on an individual operator's investment styles. The system utilizes this profile to rank stocks, and it revises the profile based on traces of operator behavior. The system automates information acquisition; it encompasses sensing, and registers input data.

The system architecture is composed of the following elements:

1. *The data processing unit* which converts raw input (i.e., current stock readings and historical trading information) into reports that contain buy and sell recommendations for the operator. It relies on the recommendation module to make appropriate suggestions for each stock based on individual operator profiles.
2. *The user modeler* which constructs these profiles is based on operator responses to previous recommendations (implicit).
3. *The information manager* records traces of an operator's interactions with the system and also maintains awareness of operator portfolios.
4. *The communication unit* manages the information into and out of the server.
5. A client contains a communication unit and a graphical user interface component.

Results from a study conducted with novice stock traders indicated that as the system learned through interaction with the operator's past behaviour, the traders' acceptance of recommendations increased. Furthermore, as the traders' began to better understand how the system operates, they also began to accept more recommendations.

Conclusions for IASs:

1. An implicit user model can be an effective and non-obstructive means of constructing a user model.
2. A learning system can improve decision support.

Reference:

Sears, A. and Schneiderman, B (1994). Split menus: Effectively using selection frequency to organize menus. ACM Transactions on Computer Human Interaction, 1(1), pp.27-51.

Overview:

This paper describes the concept of Split Menus, a means of managing information overload. In split menus, the most frequently accessed items are located above the top partition or "split", and the other items are located below the split. Split menus were implemented and tested in two in situ usability studies and a controlled experiment. In the usability studies, performance times were reduced by17% to 58% depending on the site and menus. In the controlled experiment, split menus were significantly faster than alphabetic menus and yielded significantly higher subjective preferences. It is a fully automatic system that does not require operator input for the implementation of adaptation.

Conclusions for IASs:

1. Results suggest that although automatically adapting the UI to the implicit user model improved performance, the user model may not apply to all operators (e.g., different usage patterns); it may be more effective to develop a method of providing an operator a choice between a customizable (adaptable) UI to give them the option to turn off the automatic feature.
2. Results suggest the need for an adaptive split menu (or interface) where the interface dynamically adapts based on a usage pattern (user model).

Reference:

Franklin, D., Budzik, J., and Hammond, K. (2002). Plan-based Interfaces: Keeping Track of User Tasks and Acting to Cooperate. In IUI'02, January 13-16, 2002.

Overview:

This paper describes the concept of an Intelligent Classroom, which consists of a computer system that dynamically adapts to operator actions and inputs (gesture and voice) in a classroom environment (i.e., controls camera, automatic presentation slide-switcher). The algorithms are goal-based and driven by task recognition.

<u>Intelligent Classroom</u>: The IC is an automated lecture facility prototype that serves as its own audio/visual assistant. The operator (e.g., speaker), provides a presentation, and the Classroom watches and listens, and when appropriate, assists will provide assistance. The IC keeps track of various activities pursued by the speaker as well as its own activities in control of its various autonomous components.

The representation is used three ways to accomplish a goal: plan execution (execute a plan to achieve a goal), plan recognition (match the operator's actions to a set of known plans), and projection (follow the operator's plan and project future actions). A set of agents are used to monitor, recognize, and execute some plan to accomplish an operator goal.

The system is based on the principle that the world is composed of a series of processes. A *process* is a single agent that executes a sequence of actions. It is composed of one or more discrete steps, each of which specifies a number of continuous actions and a number of discrete events. The processes are designed such that the Classroom can essentially use the same algorithm for executing a process that it used for observing the operator as the operator executes a process.

To alter the algorithm so that the Classroom can observe the operator and to follow along with the operator's plans, only a portion of the first step needs to be changed. Rather than performing the primitive actions that are a part of the step, the Classroom performs "observation" actions that complement the primitive actions.

The *Process manager* continually steps through its set of processes to keep them synchronized with the operator and revises the set of processes when required.

<u>Human-machine cooperation.</u> The operator, in executing part of a plan, expects the Classroom to do its part of the plan. A *plan* is a set of processes (often to be executed by a number of different agents) that when executed together successfully, accomplish some goal. In the Classroom, most plans have one process executed by the operator and one or two processes executed by the Classroom. This definition makes explicit the presence of other agents or exogenous events. In the Classroom, these plans attempt to express a common understanding of how a speaker and an audio/visual assistant interact.

<u>Conclusions for IASs:</u>

1. The more the system understands its operators and their tasks, the more useful the system will be.
2. The same techniques implemented in the Intelligent Classroom can be applied to a broad range of interactive applications. Refer to the paper for details on how to implement techniques.
3. The system should understand the operator's actions in the context of what it believes the operator is doing.
4. The ability to provide reason to the operator's activity is crucial to the implementation of an intelligent operator interface.
5. Plan generation and recognition are a promising means of adaptive automation and estimating pilot intent.
6. *Human-machine cooperation* can be achieved by allowing an operator, when executing a part of a plan, to expect a system to help in executing that part of the plan. A *plan* is a set of processes (often to be executed by a number of different agents) that when executed together successfully, accomplish some goal. Plans attempt to express a common

understanding of how a speaker and an audio/visual assistant interact.

Reference:

Sofge, D., Bugajska, M., Adams, W., Perzanowski, D., and Schultz, A. (2003). Agent-based Multimodal Interface for Dynamically Autonomous Mobile Robots, Technical Report prepared for Navy Center for Applied Research in Artificial Intelligence, Naval Research Laboratory, Washington,DC.

Overview:

An agent-based multi-modal interface is presented that was designed as a means for the robot/operator to request information through a “natural language interface” that uses combined speech recognition and a gesture interpretation process, among other command input modes. The dynamic allocation of tasks is based on a goal/spatial relation architecture.

The authors define “Human-centric” as a system that focuses on the needs and natural modes of interaction of the operator rather than the robot. A key feature of the interface is the use of multiple overlapping (and sometimes redundant) modes of communication between the operator and the robot. These are overlapping (and sometimes redundant) modes of communication that provide the operator with a natural interface to the system, allowing the operator to choose the mode of communication most comfortable to him/her given the current task, situation and environmental conditions. To control the robots through the autonomous robot agent, the operator interfaces with the Robot Interface Client.

Agents provide a natural and flexible means for integrating multiple interface modules together.

Conclusions for IASs:

1. Agent-based architecture can provide a natural and scalable approach to implementing a multimodal interface to control mobile robots through dynamic automation.
2. Direct communication with an agent through an interface (i.e., natural language and gestures) can be an effective means of human-machine communication.

Reference:

Funk, H.B., and Miller, C.A. (1997). Context sensitive interface design. Proceedings of the International and Interdisciplinary Conference on Modeling and Using Context (CONTEXT-97), Rio de Janeiro, Brazil, February 4-6, Federal University of Rio de Janeiro Ed., pp. 303-318

Overview:

The paper argues that three elements must exist to support effective context sensitive interfaces: 1) the ability to accurately monitor the context; 2) allows the operator to modify the control and display configuration; and 3) autonomous configuration changes within the interface. The paper discusses the aspects of context which are necessary to perform interface adaptation. A framework is provided which represents context characteristics using a vocabulary based on tasks and goals as the foundation of context representation and tracking. The RPA project is used as an example of this framework.

Conclusions for IASs:

1. The authors recognize that tasks can serve as an "appropriate aggregation tool for collecting information requirements". The authors advocate a general approach which entails that these requirements are captured by task, and then are summed across tasks to form the dynamic interface configuration.
2. The authors identify several benefits for task-based context representations:
   - Direct mapping between human actions and the interface;
   - Unsuccessful and ill-supported tasks can demonstrate what upgrades and additions to the interface or the automation should be made; and,
   - Tracking tasks which involve multiple individuals on the team, and particularly those which involve explicit communication between team members can directly support team collaboration.

5.2.2 Principles of Interaction

A number of factors enhance or inhibit the use and acceptance of Intelligent Adaptive Systems. The principles outlined in Sections 10.2.2.1 through 10.2.2.6 illustrate potential design features necessary to improve acceptance and utilisation.

5.2.2.1 Adaptive Automation

The following guidelines for the development of adaptive automation are suggested:

- Operators often expect IASs to perform the task at least as well as them. Thus, any IAS incorporated into the cockpit/vehicle must be highly effective to be accepted (Morris and Rouse, 1986);
- It is important that the operator can initiate the adaptation, even if this is normally done by the IAS (Noah and Haplin, 1986);
- It is important that the operator feels 'in control', even when the IAS is performing tasks (Morris, Rouse and Frey, 1986);
- The operator must not be confused by the intervention of the IAS, especially when the operator does not initiate the intervention (Lehner, Cohen, Thompson and Laskey, 1987);
- To avoid rapid changing of the task allocation between the operator and the IAS, a solution is to have the IAS initiate the off-loading of the task, and the operator initiate the re-capture of the task (Rouse, Geddes and Curry, 1987); and,
- The use of complex adaptive systems may also require the operator to learn new skills or re-learn familiar tasks. The ability of an operator to adapt to the new demands of using such a system will depend on the understanding of the functions and capabilities of the IAS (Morris and Rouse, 1986; Lehner, Cohen, Thompson and Laskey, 1987).

5.2.2.2 Adaptive Interface

Intelligent Adaptive Systems have important implications for the OMI. Noah and Haplin, (1986) suggest guidelines for the design of IAS OMIs:

- An IAS should reduce cognitive workload by sharing the initiative for operator-system dialogue. The IAS should volunteer information to the operator and make responses appropriate to the operator’s intent;
- The IAS should support the operator by monitoring input data for situations that indicate that the operator should be alerted and/or which suggest significant changes in the situation. The operator should be able to specify what these conditions might be;
- An IAS system should present information with progressively more detail as the situation demands and the operator should be able to control this function. The problem of data overload can be alleviated by the IAS presenting only summarised information first, and then elaborating when demanded by the operator;
- The operator should be able to rapidly reconfigure the IAS in response to changes in goals and problem-solving strategies;
- Displays and controls should operate within a metaphor that is consistent with the operator’s conceptual, or ‘mental’, model. In other words, the IAS should provide a mapping between data processing concepts and the concept within an operator’s domain that permits functions to be assessed in a natural and intuitive fashion. Indeed, a mental model is a representation formed by the operator of an IAS, based on previous experience as well as current observation. This mental model provides the operator with subsequent system understanding, and consequently dictates the level of task performance (Taylor, 1997);
- Training in the use of these IAS is necessary. It is preferable that the training be embedded within the system;
- The IAS should monitor interaction for errors in performance and suggest a corrective action, which should be based upon an understanding of the error source and the probable intent of the operator in that context;
- If the operator is to regard an IAS as trustworthy and useful, it must be able to provide some sort of explanation for its current or intended actions. For example, it may be useful to provide access to the data used to make the decision, even if the advice was only of low confidence; and,
- Intelligent Adaptive Systems should be designed to be both error-resistant and error-tolerant. Error-resistant systems are designed to prevent operators from making errors, whilst error-tolerant systems are able to recover from system errors in a safe and timely manner.

5.2.2.3 Human-System Organisation

Intelligent adaptive systems share responsibility, authority and autonomy over many system behaviours with the human operator. Indeed, the motivation for creating IASs is to reduce operator workload and information overload. However, while operators wish to remain in charge (and it is desirable for them to do so), in today's complex systems, operators cannot be fully in charge of all systems operations, especially not in the same way they have been in earlier cockpits and workstations.

Experience with these systems has consistently shown that this concept suffers from a basic sociological problem. Namely, the human operators of complex systems want to remain in charge of the equipment they use. For example, the Pilots Associate research programme developed a list of prioritised goals for a good cockpit configuration manager. Two of the top three items on the list were "Pilots remain in charge of task allocation" and "Pilots remain in charge of information presented" (Miller, Pelican and Goldman, 1999).

The question of "who is in charge" was addressed by Moss, Reising and Hudson (1984). They suggested that task and/or decision allocation should be completed according to the interaction of both mission goals and human/machine capabilities. Where tasks can only be performed by either human or machine their allocation is simple. Where either can perform a task, then the task should be allocated by consideration of "which one would perform the task better?" and "what will be the mission impact of such an allocation?" They suggest that the large data handling capabilities of computers suit them for processing the large amounts of sensor data available. This is achieved through knowledge of mission goals and operator information requirements, so that the data can be collapsed intelligently into a form readily interpreted by the operator. This would then allow the operator to use this fused data to make the high-level judgements, decisions under uncertainty, etc., at which humans are superior, thus achieving the mission goals most effectively. Authority allocation will be an essentially dynamic, goal-oriented process, dependent on the states of both team members relative to their environment.

However, a survey conducted by NASA (Tenney, Rogers and Pew, 1995) on civil pilot opinions on high level flight deck automation issues found that participants were nearly unanimous in proclaiming that the pilot will still be responsible for flying the aircraft in the future. They also showed a preference for automation that assists the pilot in problem solving, as compared to one that automatically solves problems. The majority of participants felt that the biggest needs for additional automation were to alleviate further mental workload demands imposed on them in time-constrained decision making situations. Overall, pilots in the NASA study indicated their belief for the pilot to remain in charge so that the automated systems advise rather than command.

However, a more recent study ascertained the opinions of Royal Air Force aircrew on automation and decision support that would improve mission effectiveness and SA, as well as reducing workload (Banbury, 1997). The study showed significantly different opinions as to which systems should have automation and to what level. Single-seat aircrew preferred increased automation of the defensive sub-systems to the point where little human involvement was required. This suggests that the single-seat crew had less cognitive resources available to operate the defensive systems effectively and make the appropriate defensive decisions. The general consensus of opinion was in favour of high levels of automation, however, aircrew also wanted to remain in the decision loop and have an interactive role in the systems.

A study on aircrew attitudes towards cockpit automation found that aircrew wanted high levels of automation up to the point where they could retain ultimate executive control (Enterkin, 1994). The aircrew reported an underlying reluctance to place complete trust in automated systems so that they could resume control if the system is in error or non-functional. Opinions relating to adaptive automation showed that aircrew had a more favourable opinion towards customised automation (i.e., operator-configured automation) and held a more uncertain view of intelligent automation (i.e., context-dependent automation).

There were a number of reservations voiced about customised versus intelligent automation. Participants felt that having automation levels customised to the individual may defeat the objectives of having standardised equipment, operating procedures, and training regimens. In addition, allowing bespoke cockpit display formats and configurations may negate the benefit of standardised training, such as reduced cost, and transfer of training to other platforms. Attitudes towards having automation levels specific to each mission phase were far more positive, because this aspect of customised automation can be readily implemented into training. However, the report did not solicit any opinion from pilots as to what level of automation would be desirable for each mission phase.

<u>Reference</u>:

Sheridan, T.B., and Parasuraman, R. (2006). Human-automation interaction. In R.S.Nickerson (Ed.). Reviews of Human Factors and Ergonomics, Volume 1. HFES: Santa Monica, CA.

<u>Overview:</u>

This paper reviews recent research in the area of human-automation interaction. It describes taxonomies including supervisory control of automation and function allocation, and models of human-automation interaction. The paper outlines automation-related accidents associated with inadequate feedback and misuse of automation, and evaluates the social, political, and ethical issues related to role of etiquette and trust on operator performance.

<u>Operator-automation/agent interaction:</u> The authors outline three ways that an operator can interact with a system:

1. By specifying to the automation/agent the task goals and constraints and possible trade-offs (e.g., pilots programming flight management systems);
2. By controlling the automation/agent to start, stop or modify the execution of the automatic task (e.g., clock time; abort automatic execution); and,
3. By receiving information, energy, physical objects, or substances from the automation/agent, (e.g., warning or alarm display; expert system giving advice).

Supervisory control over automated systems: A new relationship between the operator and the system is identified, whereby the operator supervises an *intelligent* but subordinate system by issuing instructions, and the subordinate executes those instructions by using the system's own memories, built-in programs, sensors and energy sources.

Delegation interfaces: In these systems, the operator delegates tasks to the system, at times of the operator's own choosing and receives feedback on their performance.

<u>Conclusions for IASs:</u>

1. The authors outline *five main categories of techniques* for implementing adaptive automation:
   - *Critical events method:* The automation is triggered by critical events (e.g., when pilot loses consciousness, the auto-pilot is automatically executed).

- *Operator performance and physiological measurements:* Automation is adapted based on an assessment of operator state. For instance, this could include using a secondary-task measurement technique to assess operator workload in a primary task or through Electroencephalographic (EEG) and Event-Related Potentials (ERPs) measurement.
- *Modeling:* A set of pre-defined rules for implementing adaptive automation.
- *Hybrid:* A mix of the other four methods.

2. The authors outline various advantages and disadvantages of the five methods:

- Critical events method is flexible as it can be coupled to mission planning, but does not account for operator requirements.
- Measurement of operator performance or physiological state can be potentially responsive to unpredictable changes in operator cognitive states. Physiological measures can be designed to be relatively unobstrusive, and have high bandwidth compared with performance measures. A disadvantage is measurement sensitivity, which needs to be established in each application domain.
- Modelling techniques can be implemented offline and easily incorporated into a rule-based expert system. However, a valid model is required and different models within the same system might give contrary decisions at any point in time.
- Hybrid methods attempt to optimize relative benefits and disadvantages of each technique, and may therefore offer the best general approach to implementing adaptive automation.
- There is a misconception in the engineering domain, that if the operator is removed from the system (with automation), then human error can be eliminated. This only shifts the focus of error and does not resolve the underlying problem.

Reference:

Linegang, M.P., Stoner, H.A., Patterson, M.J., Seppelt, B.D., Hoffman, J.D., Crittendon, Z.B., and Lee, J.D. (2006). Human-automation collaboration in dynamic mission planning: a challenge requiring an ecological approach. Proceedings of the 50th Human Factors and Ergonomics Society Conference, San Francisco, CA.

Overview:

This paper presents a model of the human-automation interaction system and examines an ecological approach to system analysis and design. According to the authors, this model provides a theory explaining the conflict source between human and automation. The authors claim that this model predicts that an ecological approach to display design would reduce that conflict.

The authors advocate a goal-based approach to adaptive systems based on a control theory framework. The human specifies goals for the automated system. The automation system then generates a set of planned actions and executes those actions. The human and the system share the role of implementing automation. That is, both the human and the system monitor the environment to identify “error” that would necessitate a modification of the plan.

The authors claim that conflicts can occur in this shared role when the operator's implicit goals (e.g., don't alert an enemy to your presence), do not match the pre-defined goals of the system (e.g., minimize fuel consumption). To minimize this conflict, displays should represent information relevant to *explicit, implicit, and pre-programmed goals*. In this way, the operator and the system can *collaborate* in optimizing the achievement of all true mission goals (explicit and implicit). The authors recommend an "ecological" approach to display design to organize information according to the natural structure of the mission environment.

<u>Mission Displays for Autonomous Systems (MiDAS)</u> This system is an example solution to resolve the conflict between the operator and the system. MiDAS applies an ecological approach to system design and involves a comprehensive analysis of the work domain, based on Work Domain Analysis (including Cognitive Work Analysis) and Ecological Interface Design.

<u>Conclusions for IASs:</u>

1. The authors advocate a goal-based approach to adaptive systems based on a control theory framework.
2. This demonstration provides evidence that the ecological analysis and design concepts based on this analysis can transform the operator's display into a tool that links abstract goals to concrete properties.
3. MiDAS is an example of an ecological approach which can allow human operators to communicate with automation systems about the linkage of abstract goals with concrete plans and properties of the environment.

<u>Reference:</u>

Taylor, R. M. (1998). The human-electronic crew: Human-computer collaborative team working. Proceedings of the 1st NATO RTO Human Factors and Medical Panel Symposium on Collaborative Crew Performance in Complex Operational Systems, Edinburgh, UK, 20-22 April 1998.

<u>Overview:</u>

This paper describes the concept of Human-Electronic Crew teamwork, whereby the electronic crew member (the electronic support system) acts as an associate or an assistant, sharing responsibility, authority and autonomy over many cockpit tasks. Various methods are suggested for ensuring that the relationship between the operator and the system is flexible and adaptive including: in-flight situation assessment and re-planning (of goals), cognitive modelling, human intent inferencing and error recognition (tracking of tasks), and the use of complex knowledge engineering and reasoning logic processes.

Please refer to Frameworks Section 8.4.1 for more detailed information on this paper.

<u>Conclusions for IASs</u>:

1. The authors advocate that it is imperative to understand the operator's role within the system to determine the appropriate system support for that role. The analysis of the operator's role can guide the system design.
2. Intelligent aiding systems (e.g., full associate system) should provide assistance with

the basic functions of assessment, planning, co-ordinating and acting (to mimic human information processing and problem-solving abilities).

3. Functional architectures are a good way to implement IAHs that support strong interactions and tight integration. That is, the behaviours required by the domains (e.g., tasks) are shared between the system and the human across the functional components.
4. In order to support an associate relationship with the system, the authors claim that function allocation should be flexible and dynamic, driven more by the situation and context, than by the preservation of a sole sources of control authority (unlike the CAMMY and CE project that are driven by pilot control).
5. Operator trust is enhanced by IAH system consistency and correctness (e.g., decisions and actions are consistent and predictable).
6. The plan-goal graph (PGG) modelling approach was developed to address the problem of intent referencing and used in the HEC model as a means to predict pilot intent. Intent recognition is achieved by differentiating the goals from the behaviour of the operator.
7. Operator errors with increased risk of severe consequences (especially without corrective action) should require assertive intervention and action aiding by the system (e.g., auto-pilot is automatically turned on when the pilot loses consciousness).
8. The system should conform to the pilots' mental model. A mental model is a representation formed by an operator of a system and/or task and is based on previous experience and current observation. This provides a basis for the operators understanding of system functionality which can influence their performance on tasks.

Reference:

Miller, C. and Hannen, M. (1998). User acceptance of an intelligent user interface: A rotorcraft pilot's associate example. In M. T. Maybury (Ed.). Proceedings of the 4th International conference on intelligent user interfaces (pp. 109-116). New York, NY: ACM Press.

Overview:

This paper details the high level architecture of the Cockpit Information Manager (of the RPA). It emphasizes how pilot behaviours are monitored, crew intent is estimated, symbols are selected and de-cluttered, windows are located, and the automated pan and zoom and the allocation of tasks are implemented.

Please refer to Frameworks Section 8.4.2.2 for more details on this paper.

Conclusions for IASs:

1. A full associate relationship approach is taken by the RPA program for providing system assistance.
2. This approach requires that pilot intent and error recognition are monitored and estimated to provide context appropriate assistance (this is done with a Crew Intent Estimator).

3. A World State or “Context” Model is used to determine context.
4. A task and goal-based approach in the form of a Task Network is used to estimate pilot intent and error recognition with pre-define tasks/goals.
5. An operator profile is used to determine pilot expectations, their information needs, etc.
6. Preliminary results from a simulation test found that the CIM behaviours are contributing to perceived pilot effectiveness, reducing workload and are gaining pilot acceptance

Reference:

Geddes, N.D., and Shalin, V.L. (1997). *Intelligent decision aiding for aviation.* Technical Report (No. ISSN 1402-7585). Prepared for Linkoping Institute of Technology, Linkpoping, Sweden.

Overview:

Intelligent decision aiding technologies (adaptive systems and automation) are reviewed in the context of the aviation domain. This report explores issues of system architecture, development and integration methods, and approaches to the test and evaluation of large-scale intelligent aiding systems. The focus is based on the Pilot’s Associate program. The following briefly describes the development strategies used to develop IAI systems:

- *Human-Centered Design (HMD) perspective:* This perspective determined that the role of the human in the system is based on an operational philosophy. It identified what types of roles humans should play in the system (e.g., as authority and agent).
- *Design Representations:* The use of Intelligent Object-Oriented Design (IOOD) is a series of steps that is well suited to transform requirements (e.g., system, operator, organization) to more abstract views of objects (refer to pages 65-68 for details on this process).
- *Iterative Design Process:* This process recognizes the need for feedback into the design and requirements process to ensure that the design of the system evolves. This process outlines a series of prototyping cycles which is a common means of organizing iterative development.
- *Application of development tools:* It was found that an iterative development is most productive when supported by a set of management, design and testing tools (e.g., Plan Goal Graph Tool, Display Analyst).

Conclusions for IASs:

1. The authors found that knowledge-based systems, such as intelligent adaptive systems, require more elaboration at higher levels of abstraction (e.g., plan-goal graphs; abstract processes, behaviours and use case templates). This can be achieved through IOOD. Object-oriented languages are well suited to transform requirements and support the development of IAH systems.
2. Complex intelligent adaptive systems require many agents and frameworks (i.e., operational knowledge representations). Interaction protocols can be used to ensure that the system operates as a whole.
3. There are now a large number of well-developed reasoning algorithms and operational knowledge representations. While a wealth of processes (i.e., algorithms) and representations is often necessary for complex systems, the authors are careful to

indicate that the system should take the form that best suits the process desired.

4. The authors have noted that the development process requires tool support (e.g., PGG) but that the tools presently available (as of 1997) fall short for knowledge-based systems. System designers must therefore anticipate the need to develop tools along with the product.

Reference:

Mooshage, O. Distelmaier, H & Grandt, M. (2002). Human Centered Decision Support for Anti-Air Warfare on Naval Platforms. In Proceedings of RTO Human Factors and Medicine Panel (HFM) Symposium held in Warsaw, Poland, 7-9 October 2002.

Overview:

This paper examines various methods to acquire, describe, formalize, and represent knowledge and problem solving strategies of domain experts for the development of rule-based intelligent decision aids in Anti-Air Warfare (AWW).

Conclusions for IASs:

1. An intelligent decision aid should support the resources specific to all stages (roles) of human information processing (i.e., based on Wickens' model of multiple resources).
2. The authors recommend that a system should provide support according to the complexity of the task at hand, the over all situation and the operator state.
3. The authors recommend that knowledge representation techniques should enable the operator to retain an adequate situational awareness. They found that certain knowledge-based techniques can provide information about how a system determined a conclusion, while other systems cannot. For this reason, neural networks are not considered a good strategy as they lack any transparency. Generic algorithms are also not appropriate due to their inherent mutation that makes them unpredictable.
4. The authors recommend that formal decision support techniques beyond rule-based support systems should be used to support the human decision maker's cognitive processes (i.e., level of information processing). Three techniques are recommended:
   - Bayesian belief networks (suitable for problems for which a substantial, representative collection of successfully solved cases is available);
   - Case-based reasoning (for classification problems for which enfolded collections of real or made up cases with correct solutions, and detailed logging of all attributes exist);
   - Fuzzy theory (can be applied to a task in which the degree of conformance can neither be set assuredly "true" or "false" but merely mapped to fuzzy sets).
5. Variables related to decision making should be identified using empirical knowledge acquisition techniques (e.g., laboratory test bed).
6. A purely rule-based support system is not capable of supporting the human decision maker in a situation in which knowledge-based acting is essential.
7. While certain knowledge-based techniques can provide auxiliary information about the way that

led to their conclusions, others cannot. For this reason, neural networks are not considered a good strategy as they lack any transparency. Generic algorithms are also not appropriate due to their inherent mutation that makes them unpredictable.

Reference:

Miller, C., Funk, H., Wu, P., Goldman, R., Meisner, J., Chapman, M. (2005). The Playbook Approach to Adaptive Automation, In Proceedings of the Human Factors and Ergonomics Society's 49th Annual Meeting, Orlando, FL

Overview:

Playbook is a human-system communication tool that allows delegated control of automation. The tool is based on a shared model of the tasks in a domain. This shared task model provides a means of human-automation communication about plans, goals, methods and resource usage, a process similar to referencing plays in a sports team's playbook. The Playbook enables operators to interact with subordinate systems with human subordinates, thus allowing for adaptive automation. This approach and its application is described through an ongoing project called Playbook-enhanced Variable Autonomy Control System™

Playbook is a specific method of implementing a delegation interaction which can be divided into two components: (1) a hierarchical task model that is compatible with levels of automation (cf. Sheridan, 1987); and (2) a planning mechanism for evaluating existing resources, plan validity, and instantiating the task models.

A shared task model is comprised of a set of *play templates* are generated by identifying a set of common tasks, grouping those tasks into plays, and enabling elements such as time and location to become task parameters.

How Playbook works. When a previously defined play is executed, the operator can select a play template and apply the parameter values as appropriate to his/her needs. Both the operator and the automation have a similar model of the sequence of tasks to execute (the shared task model).

The overall Playbook architecture consists of three components: a library of task models; a constraint-based planning engine; and an OMI.

Conclusions for IASs:

1. Findings provide support for allowing the tasking of multiple agents while keeping the supervisor in the decision-making loop, without increasing supervisor mental workload. It also suggests that the human supervisor can adapt successfully to unpredictable changes in the environment.
2. Playbook provides a complete architecture for the integration of human input, intelligent *a priori* planning, reactive planning and event handling, and ongoing vehicle control loops.
3. The authors recognize that new methodologies are still needed to build more extensive task models. For instance, Playbook task knowledge should arise from results of Cognitive Work Analysis of a task domain and then the Playbook architecture (including UI and planning components) can be used to produce useful task timeline inputs for a constructive simulation

Reference:

Onken, R. (2002). Cognitive Cooperation for the Sake of the Human-Machine Team Effectiveness. In Proceedings of RTO Human Factors and Medicine Panel (HFM) Symposium held in Warsaw, Poland, 7-9 October 2002.

Overview:

This paper is a keynote address presenting a framework for incorporating cognitive automation into a work system. A team coordination approach is suggested.

Cognitive automation is based on the comprehensive knowledge about work process objectives and goals on all goal hierarchy levels. Task options and necessary data describing the current situation in the work process are also reviewed. Cognitive automation is a prime-goal-oriented based approach.

Conclusions for IASs:

1. The authors advocate that the coordination of authority for task initiation automation requires that cooperating team members should know as much as possible from each other's performance characteristics and behavioural traits. Therefore, modelling of cognitive behaviour, in particular of human behaviour, is needed to enhance machine-human team effectiveness
2. The authors report that the success of cognitive cooperation is highly dependent on a valid model of the human operator. The validity of this model will influence the capability of the artificial cognitive units to provide appropriate aid.

5.2.2.4 Human-System Teamwork

Another important research area that should be considered for IASs is theories of teamwork. A number of the IASs discussed previously are able to learn through experience, and to anticipate the actions of the operator based on previous behaviour and mission objectives. Potentially, this increases the functional effectiveness of such a human-machine team. This concept of human and machine working as an intelligent, co-operative team is considered by many as being central to the successful application of IAS (e.g., Emerson, Reinecke, Reising and Taylor, 1988; 1990).

A model of teamwork is described by Taylor and Selcon (1993). Their model is derived from the social psychology of small group dynamics (Figure 8). Teams are considered to differ from small groups in that greater emphasis is placed on clear definition of goals, roles and structure for teams. Taylor and Selcon claim that teams have three distinctive characteristics:

1. Co-ordination of activity, aimed at performing certain tasks and at achieving specific, agreed goals. Such co-ordination is dependent on trust between team members to be successful, since trust is the mechanism which allows co-ordination of effort to take place;
2. Communication and interaction between team members; and,

3. Well-defined organisation and structure, with members occupying specific roles with associated power, authority and status, whilst exhibiting conformity and commitment to team norms and goals. Such organisation will define the allocation of functions and the locus of authority within the team.

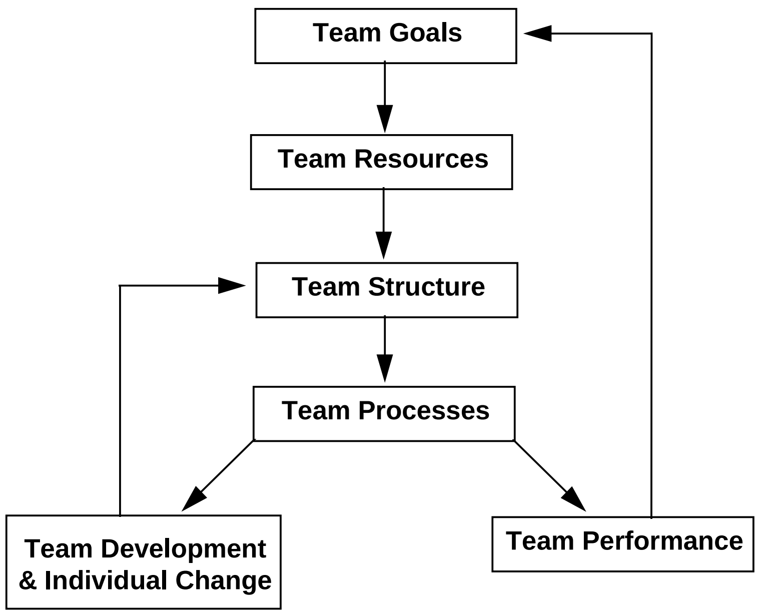


Figure 8: Model of Human-Electronic Teamwork (Taylor and Selcon, 1990, 1993).

The system of relationships between the components of teamwork can be understood in terms of the team's goals, resources, and their effects on individual team members, team development and team performance. Such a model provides the framework for considering the implementation of IASs so as to produce an effective team capable of best achieving the operational aims for which it is designed.

Implementing IASs in a way that produces a synergistic relationship with the human operator raises a number of human-computer interaction issues, the solutions which are likely to be crucial in any successful system. Foremost, among these must be considerations of where authority should be vested within the team and human trust in the system.

Reference:

Onken, R. (2002). Cognitive Cooperation for the Sake of the Human-Machine Team Effectiveness. In Proceedings of RTO Human Factors and Medicine Panel (HFM) Symposium held in Warsaw, Poland, 7-9 October 2002.

Overview:

This paper is a keynote address presenting a framework for incorporating cognitive automation into a work system. A team coordination approach is suggested.

Cognitive automation is based on the comprehensive knowledge about work process objectives and goals on all goal hierarchy levels. Task options and necessary data describing the current situation in the work process are also reviewed. Cognitive automation is a prime-goal-oriented based approach.

Conclusions for IASs:

1. The authors advocate that the coordination of authority for the initiation requires that cooperating team members should know as much as possible from each other's performance characteristics and behavioural traits. Therefore, modelling of cognitive behaviour, in particular of human behaviour, is needed to enhance machine-human team effectiveness
2. The authors report that the success of cognitive cooperation is highly dependent on a valid model of the human operator. The validity of this model will influence the capability of the artificial cognitive units to provide appropriate aid.

Reference:

de Reus, A.J.C., Roessingh, J.J.M., and Pouw, F.C.M. (2006). Modelling Approach to Teamwork Issues in a UAV Ground Control Station. In Proceedings of RTO Human Factors and Medicine Panel (HFM) Symposium held in.

Overview:

This paper discusses a high-level qualitative model for teamwork as a means to capture the teamwork processes. This model in turn provides the basis for lower level Bayesian Belief Network models that focus on mishap scenarios.

Model development process:

First, a team task analysis was undertaken, which resulted in the identification of skills for teamwork in UAV operations. Secondly, using the high level model, different lower level models were defined in the form of a Bayesian Belief Networks. The goal of the modelling effort, taking the two-step approach, is to estimate the relative contribution of team skills in UAV mishaps, with focus on such skills as team resource management skills, team decision-making, insight in the automation concept, and (shared) knowledge of standard operating procedures, including selection of the appropriate procedures. The Bayesian Belief Networks was found to be a useful tool to structure task allocation, task sharing, team composition, procedures, and OMIs from a teamwork perspective.

Conclusions for IASs:

1. Teamwork concepts should be considered when designing systems that require human operators to simultaneously control several functions at various working positions, such as controlling multiple UAVs.
2. This paper demonstrated that Bayesian Belief Networks can be used to structure task

allocation, task sharing, team composition, procedures, and OMIs from a teamwork perspective.

Reference:

Franklin, D., Budzik, J., and Hammond, K. (2002). Plan-based Interfaces: Keeping Track of User Tasks and Acting to Cooperate. In IUI’02, January 13-16, 2002.

Overview:

This paper describes the concept of an Intelligent Classroom, which consists of a computer system that dynamically adapts to operator actions and inputs (gesture and voice) in a classroom environment (i.e., controls camera, automatic presentation slide-switcher). The algorithms are goal-based and driven by task recognition.

Intelligent Classroom: The IC is an automated lecture facility prototype that serves as its own audio/visual assistant. The operator (e.g., speaker), provides a presentation, and the Classroom watches and listens, and when appropriate, assists will provide assistance. The IC keeps track of various activities pursued by the speaker as well as its own activities in control of its various autonomous components.

ROLE	AGENT	AUTHORITY
ACQUIRE	-	-
ANALYZE/ PRESENT	-	-
DECIDE	💻 😐	💻 😐
ACT	💻	💻 😐

The representation is used three ways to accomplish a goal: plan execution (execute a plan to achieve a goal), plan recognition (match the operator’s actions to a set of known plans), and projection (follows the operator’s plan and projects future actions). A set of agents are used to monitor, recognize, and execute some plan to accomplish an operator goal.

The system is based on the principle that the world is composed of a series of processes. A *process* is a single agent that executes a sequence of actions. It is composed of one or more discrete steps, each of which specifies a number of continuous actions and a number of discrete events. The processes are designed such that the Classroom can essentially use the same algorithm for executing a process that it used for observing the operator as the operator executes a process.

To alter the algorithm so that the Classroom can observe the operator and to follow along with the operator’s plans, only a portion of the first step needs to be changed. Rather than performing the primitive actions that are a part of the step, the Classroom performs “observation” actions that complement the primitive actions.

The *Process manager* continually steps through its set of processes to keep them synchronized with the operator and revises the set of processes when required.

Human-machine cooperation. The operator, in executing part of a plan, expects the Classroom to do its part of the plan. A *plan* is a set of processes (often to be executed by a number of different agents) that when executed together successfully, accomplish some goal. In the Classroom, most plans have one process executed by the operator and one or two processes executed by the Classroom. This definition makes explicit the presence of other agents or exogenous events. In the Classroom, these plans attempt to express a common understanding of how a speaker and an audio/visual assistant interact.

Conclusions:

1. The same techniques implemented in the Intelligent Classroom can be applied to a broad range of interactive applications. Refer to the paper for details on how to implement techniques.
2. The system should understand the operator's actions in the context of what it believes the operator is doing.
3. The ability to provide reason to the operator's activity is crucial to the implementation of an intelligent operator interface.
4. Plan generation and recognition are a promising means of adaptive automation and estimating pilot intent.
5. *Human-machine cooperation* can be achieved by allowing an operator, when executing a part of a plan, to expect a system to help in executing that part of the plan. A *plan* is a set of processes (often to be executed by a number of different agents) that when executed together successfully, accomplish some goal. Plans attempt to express a common understanding of how a speaker and an audio/visual assistant interact.

Reference:

Wolfman, S.A., Lau Pedro Domingos, T and Weld, D.S. (2001). Mixed Initiative Interfaces for Learning Tasks: SMARTedit Talks Back. In proceedings of IUI'01, January 14-17, 2001, Santa Fe, New Mexico, USA.

Overview:

An interface for machine learning is proposed. The paper describes a variety of interaction modes that enhance the learning process and presents a decision-theoretic framework, called DIAManD, for choosing the best interaction.

The authors propose that machine learning systems should closely resemble human teacher-student relationships and follow the example of the proactive yet considerate student. For instance, the system should ask questions, propose examples and solutions, and relate its level of knowledge when appropriate to make the interaction more effective.

DIAManD is a system for selecting among various interaction modes using a multi-attribute utility function. The interaction modes provide a variety of methods for an operator to interact with the system. The system selects from a set of interaction modes the mode it judges most appropriate based on attribute vectors. The best of these modes is presented to the operator and controls the next stage of discourse, updating the state of the learner. The modes are then rescored based on the new state of the learner.

Conclusions for IASs:

1. The authors advocate a mixed-initiative interface in which the machine learner and human operator equally share responsibility for guiding the learning process.
2. A learning system should have several modes of interaction with the operator to acquire the concepts more quickly (e.g., through judicious choice of the example to classify, as in active learning) and should allow the operator to have more control over the learning process. See paper for details on interaction modes.
3. A mixed-initiative framework (e.g., DIAManD), where the learner and human operator are each participants in a dialogue, could improve the learner's hypothesis with minimal effort on the part of the operator.
4. To facilitate rapid learning, the interface should provide some mechanism for feedback to the learning system on particularly poor interaction mode choices (the feedback model is further described in the article).

Reference:

Eggleston, R.G., Roth, E.M., and Scott, R.A. (2003). A Framework for Work-Centered Product Evaluation. In proceedings of the 47th Human Factors and Ergonomics Society Conference, Denver.

Overview:

A comprehensive work-centred evaluation framework that assesses new technology for their value in supporting human performance is described. A key feature of the framework is that it encompasses: usability, usefulness and impact. This concept is illustrated through a work-centred support system prototype. The framework is detailed in Young, M.J. and Eggleston, R.G. (2002).

In the WCSS prototype, software agents are designed as small, independent chunks of software that address tasks as separately controlled and modifiable modules. This enables software components to be organized according to functional elements of work in a particular domain.

A detailed domain analysis was performed to map domain work requirements and systematically allocate tasks to human and software agents.

Structuring agents in functional terms provides a concrete vocabulary of concepts and metaphors that can be shared among software engineers, cognitive engineers, and operators.

Two types of interfacing agents are used in the prototype. The "visibility" of the agents is based on the task:

- Agents organized around domain work. These include forecasting agents, region analysis and mission analysis agents, which are agents that operators "delegate" work to; they have no personality.
- Agents that operators can access if needed. These include data acquisition agents.

Conclusions for IASs:

1. *Cognitive work analysis* is an effective means of establishing system requirements. The authors advocate that sources of cognitive and collaborative demands should be analyzed in the applied domain and should involve close interaction among the cognitive engineers, software developers and domain practitioners.
2. *Automated agents* should act as 'team players'.
3. *Visibility of agents:* Automated agents need to be observable (or transparent/visible) so that operators are able to determine the current state of the automated agents, and understand what the agents will do next relative to the state of the task. The amount of "visibility" required is questionable (i.e., the issue of trust and mistrust can occur or fully visible such as the Microsoft "PaperClip" which takes advantage of assistant and subordinate metaphors)
4. Humans should have control and be able to re-direct the software agents as task requirements change.
5. A system needs to support multiple facets of individual cognitive and collaborative work. This involves consideration of problem-solving/decision-making aspects of work, activities involved in creating work products, processes involved in collaborative work, and the cognitive effort involved in tracking and managing multiple intertwined work activities.
6. Object-oriented design techniques are useful in facilitating collaboration between operators, cognitive engineers, and software engineers (although as system complexity increases, the operator can lose sight of the big picture).
7. Agent-based architectures provide potential for operator-accessible descriptions of domain objects, workflow, and large-scale interactions between domain objects.

Reference:

Sheridan, T.B., and Parasuraman, R. (2006). Human-automation interaction. In R.S.Nickerson (Ed.). Reviews of Human Factors and Ergonomics, Volume 1. HFES: Santa Monica, CA.

Overview:

This paper reviews recent research in the area of human-automation interaction. It describes taxonomies including supervisory control of automation and function allocation, and models of human-automation interaction. The paper outlines automation-related accidents associated with inadequate feedback and misuse of automation, and evaluates the social, political, and ethical issues related to role of etiquette and trust on operator performance.

Conclusions for IASs:

1. *Levels of automation (assigned agent: operator or system) and initiation of task.:* The authors recognize that there are various degrees of automation appropriate to different contexts, and that different process stages (i.e., information acquisition, analysis, decision about action, implementation of action) of a complex system are appropriately automated to different degrees.
2. *Proper feedback and communication.* Systems should provide the operator with information concerning automation modes, system states, and future automated actions. This may

improve human-machine communication and therefore potentially enhance system performance.

3. *Ecological Interface Design displays for non-routine conditions.* EID displays may be particularly helpful for operator-automation interaction under non-routine conditions. When unexpected events occur, an operator-automation display interface is required that allows for quick comprehension of system state and rapid action.
4. The authors note that one of the main problems of operator-system automation is not one of authority or autonomy but of cooperation and observability. Cooperation means a shared mental representation between the operator and the system.
5. The authors identify the “mixed-initiative problem”; as systems become more complex, more and more control loops are required and the probability of these control loops interfering with each other increases. This can occur if the operator cannot see what actions the other control loops are performing or what loops are being accessed from the same resource pool.

5.2.2.5 Supervisory Control over Initiation of Adaptation

Supervisory control over automated systems is a form of human-machine relationship; the human supervises an *intelligent* but subordinate system by issuing instructions, and the subordinate executes those instructions by using their own memories, built-in programs, sensors and energy sources. These systems are also known as d*elegation interfaces;* operators delegate tasks to the system, at times the operator chooses, and receives feedback on their performance.

Reference:

Miller, C. and Goldman, R. (1999). Tasking interfaces: Associates that know who's the boss. In J. Reising, R. M. Taylor and R. Onken (Eds.). The human electronic crew: The right stuff? Proceedings of the 4th joint GAF/RAF/USAF workshop on human-computer teamwork, Kreuth, Germany (Technical report AFRL-HE-WP-TR-1999-0235 pp.97-102). Wright Patterson AFB, OH: Air Force Research Laboratory.

Overview:

This paper describes the techniques, adapted from the “associate” (PA) research, used for the construction of tasking interfaces. They present initial work on a solution, which allows human operators to interact with advanced automation at various levels. According to this model, tasked systems should always be sub-ordinate, but must know enough about the tasks in the domain. The authors claim that instructing these “tasking interfaces” is vastly easier than instructing traditional automated systems. Concepts are described and discussed in the context of a tasking interface for UAVs.

Playbook OMI

This is an interface that allows the operator to inspect and interact with the system (through a task model) by “calling plays” and activating tasks at various levels and sub-levels. Through this interface, the operator will graphically instruct a full or partial plan for the mission by specifying the tasks to be performed, or goals to be accomplished by the system (Figure 6).

Playbook Framework:

The framework is composed of four primary components:

- **Playbook OMI**
- **Mission Analysis**. A projective planning system which is capable of understanding instructions from the operator through the OMI.
- **Event Handling.** All accepted plans are passed from the mission analysis module to “even handling” where plans can be adjusted in real-time.
- **Control algorithms**. Executes the instructions.

This framework is based upon and interacts with a Shared Task Model Infrastructure, which can facilitate human-system coordination.

Conclusions for IASs:

1. The authors stress that a usability evaluation of the tasking interface GUI (and all system interfaces) is required.
2. The authors warn that tasking interfaces should not rely on a predefined set of task models, but dynamic ones. The operator should be able to create novel tasks and to store components of models which are useful.
3. The authors acknowledge that their task network representation is weak in its coding of goals, which are seen as a critical component of any tasking interface.
4. Operators need sufficient training for interacting with the tasking interface.
5. A delegated interface may increase operator acceptance; that is, by enabling a system to behave more like an intelligent subordinate, operators may be more tolerant of their weaknesses and more acceptable of their capabilities in a controlled setting.

Reference:

Parasuraman, R., and Miller, C. (2006). Delegation interfaces for human supervision of multiple unmanned vehicles: Theory, experiments and practical applications. Advances in Human Performance and Cognitive Engineering Research, 7, 251-266

Overview:

This paper provides a framework for human supervision of multiple UAVs based on the concept of delegation. Delegation type interfaces represent a form of adaptive or adaptable automation. This paper claims that delegation interfaces can retain the benefits of automation, while minimising some costs. Results from laboratory experiments are presented to illustrate the influence of delegated interfaces on operator performance and acceptance.

Conclusions for IASs:

1. Results show that these interfaces allow operators to respond effectively to unpredictable changes, which was associated with the flexibility afforded by delegation interfaces.
2. Slightly higher workload was found when participants had flexible access to both manual control and automated plays.
3. Flexible interfaces were preferred over full or no automation.
4. Findings suggest that while flexible interfaces are preferred, workload can still be increased. Therefore, a balance between operator acceptance and workload should be maintained.

Reference:

Cummings, M.L. (2004). The need for command and control instant message adaptive interfaces: Lessons learned from tactical Tomahawk human-in-the-loop simulation. CyberPsychology and Behaviour, 7(6), 653-661

Overview:

This paper examines human performance issues for supervisory control of the Navy's new Tactical Tomahawk missile. Measurements of operator situation awareness and workload through a secondary tasking were taken through an embedded instant messaging program. Discussed are the first attempts to quantify human supervisory command and control performance degradation as a result of interference from an instant messaging secondary tasking.

In the course of human-in-the-loop experiments, two performance measures were taken through the instant messaging interface: 1) secondary tasking as a measure of workload; and 2) situation awareness. Performing a secondary tasking is a commonly used workload measurement tool that requires a subject, assigned to a primary task, to use any spare mental capacity to attend to a secondary task.

Results revealed that some subjects fixated on the real-time instant messaging secondary task instead of the primary task of missile control, leading to the overall degradation of mission performance as well as a loss of SA. To effectively address the interruption problem in instant messaging, one challenge was to develop an adaptive system in which the computer schedules interruptions to occur in periods of low interaction, which in accordance to Norman’s model, would occur after the conclusion of evaluation and before a new goal is formed.

Conclusions for IASs:

1. The authors advocate that *Norman’s model,* which outlines seven stages of operator activity (establishment of a goal, forming of an intention, specifying an action, executing this action and then evaluation of this action which includes perception, interpretation, and evaluation of results in comparison to expectation), identifies that adaptation should occur after the conclusion of an evaluation and before a new goal is formed.

Reference:

Miller, C. (2005). Using Delegation as an Architecture for Adaptive Automation. Technical Report (No. AFRL-HE-WP-TP-2005-0029).

Overview:

A 3D model framework for adaptive automation, referred to as "Levels of Delegation", is described.. Delegation implies that a subordinate is given the responsibility to perform a task (with its subtasks), along with some authority to decide how to perform that task, as well as access to resources with some authority to decide how to use them to perform the task. This paper describes the use of this framework within an application called Playbook.

The "Delegation Framework" has three dimensions, AAA: Level of Authority, Level of Abstraction and Level of Aggregation. These dimensions define a *Delegation Space* of human-automation relationships within which delegation occurs and can be characterized. The three scales must be used to specify four variables which define the delegation space: the level of abstraction and the level of authority on it, and the level of aggregation and the level of authority on it.

Below is a description of each dimension:

- *Levels of Authority*. Full, inform, override, approval, recommend, monitor, none.
- *Level of Abstraction.* Automation can have responsibility for higher- or lower-level tasks within the task hierarchy.
- *Level of Aggregation.* Identifies how much (and/or which type) of resource each actor is authorized to use.

Conclusions for IASs:

1. All three dimensions may not be available or relevant to every system or every interaction, but the authors advocate that the model needs to be rich enough to encompass them.

Reference:

Moray, N., Inagaki, T. & Itoh, M. (2000). Adaptive automation, trust, and self-confidence in fault management of time-critical tasks. Journal of Experimental Psychology: Applied, 6, 44-58

Overview:

A study was conducted to examine how supervisory control over automation influences fault diagnosis as well as its effect on the negotiation that occurs between the operator and the system. Results are interpreted in relation to the Sheridan-Verplank scale, Inagaki's theory of situation adaptive automation, and the work of Lee, Moray and Muir on human intervention in automated systems.

Sheridan-Verplan scale: A taxonomy to describe who (human or system) performs a particular task and who has control over the allocation of that task.

Conclusions for IASs:

1. Mode of control (allocation of task and initiation) depends on the goal of the operator. For instance, in a fast-paced environment that requires quick control, automation may be more appropriate.
2. To decide which agent (human or system) has final authority, the costs and payoffs with different outcomes should be examined.
3. In at least some time-critical situations, overriding authority should be given to system, and appropriate sensors and safe decision rules should be implemented (e.g., 20-min rule in nuclear industry).
4. Trust is strongly affected by system reliability, while self-confidence is not, at least in systems where operators can distinguish which tasks are accomplished manually from those performed automatically.
5. There is little effect of unreliability, if reliability is at least 90%.
6. For effective performance and fault management, adaptive automation in real-time is necessary.

5.2.2.6 Designing the Nature of the Human-System Interaction

Studies have examined the effects of providing software agents with human-like attributes (e.g., etiquette, personality) to improve the quality, and therefore the effectiveness, of human-system interactions. Studies have also investigated cover the social, political and ethical issues relating to the use of agents.

Reference:

Armentano, M., Godoya,D. and Amandi, A. (2006). Personal assistants: Direct manipulation vs. mixed initiative interfaces. International Journal of Human-Computer Studies 64 (2006) 27–35

Overview:

This paper explores new mixed-initiative metaphors to enhance an operator's ability to directly manipulate interfaces. Mixed-initiative interaction is referred to as a flexible interaction strategy in which agents are used to manage information overload. A study evaluating how the interaction metaphor can affect the operator perception of agent capabilities is reported.

The mixed-interface is the "PersonalSearcher", an intelligent agent that builds an operator profile implicitly by observing operator behaviour while operators are performed regular activities on the Web. An agent is able to deduce the topics an operator is interested in to create an operator profile by using a content-based analysis of the information extracted by observation.

The study compared two interfaces: 1) an operator interacts with the interface directly and has no control over displayed suggestions (automation) and 2) an operator interacts with an animated "agent" instead of the interface and has control over suggestions (mixed-initiative).

Results indicate that the mixed-initiative interface increased situational awareness (i.e., operators noticed improvements in the agent suggestions over time), but that participants were more critical of suggestions.

Conclusions for IASs:

1. Mixed-initiative interfaces (e.g., direct interaction with an agent) can increase situational awareness and develop a better mental model of the system.
2. Designers must be careful when designing mixed-initiative interfaces to ensure a proper mental model of the system is achieved.

Reference:

Sheridan, T.B., and Parasuraman, R. (2006). Human-automation interaction. In R.S.Nickerson (Ed.). Reviews of Human Factors and Ergonomics, Volume 1. HFES: Santa Monica, CA.

Overview:

This paper reviews recent research in the area of human-automation interaction. It describes taxonomies including supervisory control of automation and function allocation, and models of human-automation interaction. The paper outlines automation-related accidents associated with inadequate feedback and misuse of automation, and evaluates the social, political, and ethical issues related to role of etiquette and trust on operator performance.

Operator-automation/agent interaction: The authors outline three ways that an operator can interact with a system:

4. By specifying to the automation/agent the task goals and constraints and possible trade-offs (e.g., pilots programming flight management systems);
5. By controlling the automation/agent to start, stop or modify the execution of the automatic task (e.g., clock time; abort automatic execution); and,
6. By receiving information, energy, physical objects, or substances from the automation/agent, (e.g., warning or alarm display; expert system giving advice).

Supervisory control over automated systems: A new relationship between the operator and the system is identified, whereby the operator supervises an *intelligent* but subordinate system by issuing instructions, and the subordinate executes those instructions by using the system's own memories, built-in programs, sensors and energy sources.

Delegation interfaces: In these systems, the operator delegates tasks to the system, at times of the operator's own choosing and receives, feedback on their performance.

Conclusions for IASs:

1. *The role of social etiquette.* The authors found that implicit codes of behaviour between individuals in a social setting may also play a key role in operator-system relations. For instance, it should not be assumed that every operator is the same; the machine should be sensitive and adapt to the individual, cultural, social, and contextual differences. In addition, automation should be presented following good 'etiquette' (social mores that apply to people may also apply to intelligent systems).
2. *Proper feedback and communication.* Systems should provide the operator with information

concerning automation modes, system states and future automated actions. This may improve human-machine communication, and therefore potentially enhance system performance.

3. *Ecological Interface Designed displays for non-routine conditions.* EID displays might be particularly helpful for operator-automation interaction under non-routine conditions. When unexpected events occur, an operator-automation display interface is required that allows for quick comprehension of system state and rapid action.
4. The authors note that one of the main problems of operator-system automation is not one of authority or autonomy, but of cooperation and observability; cooperation means a shared mental representation between the operator and the system.
5. The authors identify the “mixed-initiative problem”; as systems become more complex, more control loops are required and the probability of these control loops interfering with each other increases. This can occur if the operator cannot see what actions the other control loops are performing, or what loops are being accessed from the same resource pool.

Reference:

Gallimore, J. J. and Prabhala, S. (2006). Creating Collaborative Agents with Personality for Supervisory Control of Multiple UCAVs. In Proceedings of RTO Human Factors and Medicine Panel (HFM) Symposium held in Biaritz, France.

Overview:

This paper outlines research to develop a systematic approach for investigating the development of computer agents with personality as a means of improving collaboration between humans and automation in a UCAV control task.

The authors define agent personality as a system that interacts with the operator by adhering to human modes of communication (i.e., action, language, and behavior). To investigate possible interaction modes, a discrete simulation was developed for operators to interact with two computer agents, with differing ‘personalities’ in a UCAV supervisory control task. One agent was modeled to be high in extroversion, agreeableness, conscientiousness, intellect, and emotional stability (i.e., low neuroticism). The other was modeled to be lower on these dimensions. A third condition included a system with no personality. For example, in CAP-A, the computer agent greets the human operator by specifically calling them by their name in a friendly tone, whereas CAP-B greets the human operator by just saying hello in a monotone voice. The no-personality condition gives no verbal greeting.

Conclusions for IASs:

1. Although not significant, results indicate that humans do perceive personality in the collaborative computer agents and human performance was enhanced when they were incorporated into a UCAV supervisory control task.

Reference: Lee, K.M. and Nass, C. (2003). Designing social presence of social actors in human computer interaction. Proceedings of CHI 2003, April 5-10 2003, Fort Lauderdale, FL.
Overview: This paper outlines a study to examine the effects of interaction between operator factors and media factors on feelings of “social presence”. In this paper, the authors explore the effects of personality on feelings of social presence. To demonstrate the strength of these effects, they explore the use of synthetic speech. Results from the study found that operators had automatic social responses to artificial representations with “humanistic properties” such as language and personality. • Operators (especially extrovert operators) felt stronger social presence when they heard a computer voice manifesting a personality similar to their own than when the voice did not match their personality, even when the voices were clearly synthetic (similarity effect). • Both of the experiments showed that a voice suggesting an extrovert personality induced a greater sense of social presence than a voice that sounded like an introvert. While still an open question, current research suggests that humans have an automatic tendency to be very liberal in assigning humanity to an artificial stimulus, as long as they have at least minimal human features and if social rules governing human-to-human interaction Are followed.
Conclusions for IASs: 1. Results from the study indicate that customization of a computer voice according to an operators’ personality will increase feelings of social presence.
Reference: Sofge, D., Bugajska, M., Adams, W., Perzanowski, D., and Schultz, A. (2003). Agent-based Multimodal Interface for Dynamically Autonomous Mobile Robots, Technical Report prepared for Navy Center for Applied Research in Artificial Intelligence, Naval Research Laboratory, Washington, DC.
Overview: An agent-based multi-modal interface is presented that was designed as a means for the robot/operator to request information through a “natural language interface” that uses combined speech recognition and a gesture interpretation process, among other command input modes. The dynamic allocation of tasks is based on a goal/spatial relation architecture. The authors define “Human-centric” as a system that focuses on the needs and natural modes of interaction of the operator rather than the robot. A key feature of the interface is the use of multiple

overlapping (and sometimes redundant) modes of communication between the operator and the robot. These are overlapping (and sometimes redundant) modes of communication that provide the operator with a natural interface to the system, allowing the operator to choose the mode of communication most comfortable to him/her given the current task, situation and environmental conditions. To control the robots through the autonomous robot agent, the operator interfaces with the Robot Interface Client.

Agents provide a natural and flexible means for integrating multiple interface modules together.

Conclusions for IASs:

1. Agent-based architecture can provide a natural and scalable approach to implementing a multimodal interface to control mobile robots through dynamic automation.
2. Direct communication with an agent through an interface (i.e., natural language and gestures) can be an effective means of human-machine communication.

Reference:

Serenko, A. (2007). Are interface agents scapegoats? Attributions of responsibility in human–agent interaction. Interacting with Computers, 19, 293–303

Overview:

This paper presents research to understand the behavior of interface agent operators. Several conclusions are presented for understanding operator-system interaction.

Interface agents: The authors describe interface agents "as an intermediary between a person and various components of a computer system". They are used as a communication tool. Researchers have begun experimenting with the incorporation of animated, human, or cartoon-like interface agents in GUIs.

Social psychology framework for human-agent interaction: The authors recommend the use of social rules, behaviours and expectations for interface agents to mimic social principles of human-human communication.

Conclusions for IASs:

1. Interface agents can be used to emphasize the autonomy of software systems.
2. The area of social psychology offers a strong theoretical framework that may be successfully utilized to study human–agent interaction.
3. Agent designers should be aware that the more autonomous interface agents become, the more responsibility operators will assign to agents if they fail to deliver what is expected.
4. When an agent that possesses a high degree of autonomy helps a person complete a computer-related task successfully, an individual is willing to acknowledge the contribution of the agent.
5. Life-like agents may trigger natural behavior in operators.

Reference:

Prendinger, H., Ma, C., Ishizuka, M. (2007). Eye movements as indices for the utility of life-like interface agents: A pilot study. Interacting with Computers, 19, 281–292.

Overview:

This paper outlines a pilot study that compared three types of media: an animated agent, a text box, and speech only. Authors propose a different approach to evaluating animated agents, one that is based on eye movement behavior of operators interacting with the OMI. The operators do not manipulate the interface. The authors argue that operators merely watching a presentation interact, even involuntarily, with their eye movements.

Physiological signals as an evaluation method for OMIs and as an input modality: The eye movement data was analyzed for diagnostic use (as a means to examine the operator's attention to evaluate the usability of interfaces), and for interactive use (a system responds to the observed eye movements and can thus be seen as an input modality).

The investigation of eye movements revealed that deictic gestures by the agent are more effective in directing the attentional focus of subjects to relevant interface objects than the media used in the two control conditions, at a slight cost of distracting the operator from visual inspection of the object of reference. The results also demonstrate that the presence of an interface agent seemingly triggers natural and social interaction protocols of human operators.

Conclusions for IASs:

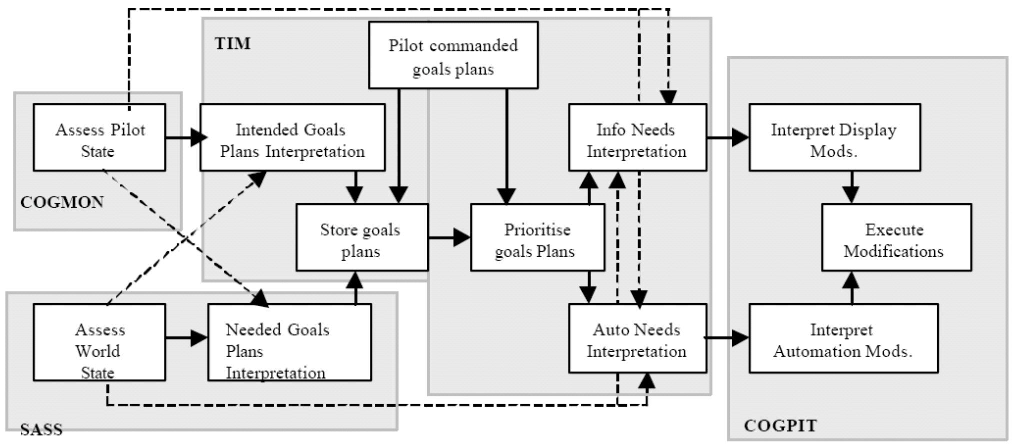
1. Physiological signals can be used as an evaluation method for OMIs and as an input modality.
2. Eye movement data might offer valuable information relevant to the utility of life-like agents.
3. The usability of interfaces can be assessed using eye movements.
4. The tracking of eye movements can capture an operator's interaction with the system in real time, which is hard to accomplish using post-experiment questionnaires.

5.2.3 Example of Human-System Teamwork – Tasking Interface Manager (Cognitive Cockpit)

The Cognitive Cockpit project included research and development of a cockpit interface sub-system for managing the outputs of the pilot aiding system, the pilot cognition monitoring system, and the interaction with the task automation. The most effective manner of ensuring that the pilot retains control of the mission at all times is to allow the pilot to interact with the automation and aiding through a Tasking Interface Manager. A TIM is considered to be necessary for the fully integrated system to ensure that the pilot's tasks, workload and cockpit control/display interfaces are managed effectively (see Bonner, et al., 2000).

The TIM is based on the Army's Rotary Pilot's Associate programme and the Air Force's Pilot's Associate programme (Miller, Pelican, and Goldman, 1999). A tasking interface allows a pilot to task automation in the same manner that an intelligent, knowledgeable, subordinate crewmember might be tasked. It will require the development of an intuitive cockpit control/display interface that provides the required pilot control of levels of task automation.

The TIM utilises information from the monitoring and analysis of the mission tasks (i.e., SASS) and from pilot state monitoring (i.e., COGMON) to drive intelligent adaptive automation and information presentation (i.e., COGPIT), as well as task and timeline management in accordance with the requirements of the mission plan. The functional architecture of the TIM comprises twelve functions, with a flow of information and control across the functions as illustrated by Figure 9. The arrows represent the flow of information



across functions; the solid arrows represent primary information and the dashed arrows represent secondary information.

Figure 9: Functional Architecture of the Tasking Interface Manager (from Bonner, Taylor, Fletcher and Miller, 2000).

The functional architecture of the TIM affords a system's four main capabilities:

1. *Shared Task Model.* In order for the TIM to be able to determine information and automation needs, the state of the mission plan needs to be known. This involves tracking the tasks that are occurring. In order to achieve this, it is essential that an operator's goals and plans be encoded and tracked, and that the model of current and planned tasks is dynamically modified to keep pace with unfolding events. The use of a task model, shared by both the operator and the knowledge-based planning system, affords a high level of co-ordination between the operator and the system;

2. *Task Tracking.* A key capability of the TIM identifies the need for a full goal/plan tracking capability, which allows the system to track any task undertaken by the operator; specifically those tasks that are instantiated in the mission plan. There are two critical requirements of any goal/plan tracking system; it must be explicit (i.e., visible to the operator) and interactive (i.e., the operator must be able to directly input or over-ride tasks).

3. *Communication of Intent.* Another capability of the TIM is to allow the operator to interact with advanced automation flexibly at a variety of levels. This allows the operator to smoothly vary the amount of automation used depending on variables such as time

available, workload, criticality of the decision, and degree of trust; these variables are known to influence human willingness and accuracy in automation use. There are three primary challenges involved in the construction of a TIM:

a. A shared vocabulary must be developed, through which the operator can flexibly delegate tasks to the automation, and the automation can report how it intends to perform those tasks;

b. Sufficient knowledge must be built into the interface to enable making intelligent choices within the tasking constraints imposed by the operator. This is the role of the information, and automation needs interpreters as illustrated in Figure 1; and,

c. One or more interfaces must be developed which will permit inspection and manipulation of the tasking vocabulary to delegate tasks and review task elaborations in a rapid and easy fashion. The goal is to allow the operator to communicate tasking instructions in the form of desired goals, tasks, partial plans or constraints in accordance with the task structures defined in the shared task model. For example, Miller (2005) developed prototype tasking interfaces based on a playbook metaphor (Section 8.3.3) whereby a set of available plans are described and visualised in a comparatively limited vocabulary of previously defined 'plays' that can then be adapted rapidly to the current context. The TIM uses a variation of the playbook metaphor.

4. *Adaptive Aiding and Automation.* Analysis of the requirement for an operator to authorise and control automation levels through the TIM has led to the development of the Pilot Authorisation and Control of Tasks system. The PACT system uses military terminology (i.e., Under Command, At Call, Advisory, In Support, Direct Support, and Automatic) to distinguish realistic operational relationships for five aiding levels, with progressive pilot authority and computer autonomy, supporting situation assessment, decision making and action (Figure 10). The operator is able control this allocation through the following:

a. Pre-set operator-preferred defaults;

b. Operator selection during pre-flight planning;

c. Changed by the operator during in-flight re-planning; and,

d. Automatically changed according to operator agreed, context-sensitive adaptive rules.

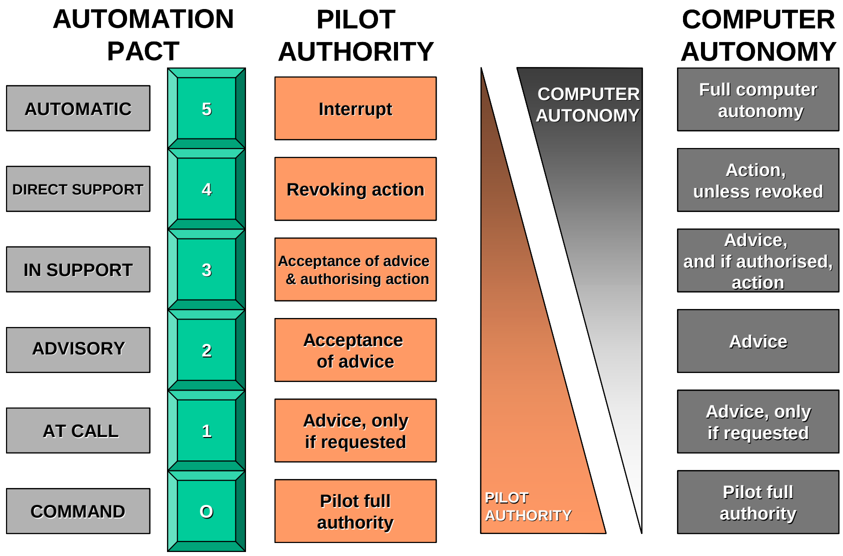


Figure 10: Summary of PACT levels (from Bonner et al., 2000).

5.2.4 Design Issues for 'Real-time' Systems

The use of an IAS in many military contexts (e.g., aviation) requires aiding and interaction in real time. In real-time operations the correctness of a system is dependent not only on the correctness of its result, but also on meeting stringent timing requirements. The deadlines for tasks that a real-time system must perform can be characterised as hard, firm, or soft. If a hard deadline is not met then the consequences are usually disastrous. Failure to meet a firm deadline means that the results of the computation have no utility. Soft deadlines mean the results of the computation are still useful after the deadline has elapsed, but have decreasing utility as a function of the time elapsed (Hayes-Roth, 1991).

The following requirements for the real-time operation of IASs can be used in addition to those in the previous section (Hayes-Roth, 1991).

5.2.4.1 Cognitive Versatility

- *Multi-faceted expertise*. The IAS should be able to perform different types of reasoning tasks in an attempt to solve problems in a variety of domains utilising a number of problem-solving techniques;
- *Concurrent reasoning activities*. The IAS must be capable of simultaneous reasoning about a number of concurrent activities;
- *Incremental reasoning*. The IAS must be able to integrate information over time to produce an accurate assessment of the current situation; and,
- *Explanation.* The IAS should be able to explain all aspects of its behaviour in the time available.

5.2.4.2 Management of Integration

- *Functional asynchrony and parallelism*. The IAS must investigate anomalies, and also perform routine actions within specified time limits;
- *Continuous operation*. The IAS must be capable of functioning over extended time periods; and,
- *Functional Integration*. The IAS should be able to perform accurate reasoning even where certain conditions affect normal output of the reasoning process (e.g., recommendations may differ as a function of weapons fit).

5.2.4.3 Management of Complexity

- *Selective attention*. The IAS may encounter situations in which it cannot process all the data in real-time. Therefore, the IAS must be able to make choices about which data are the most important and disregard extraneous data. However, it is imperative that the IAS still be alert to new data that might be critical to the current task;
- *Automatic performance*. The IAS must be able to deal with complex anomalies or situations whilst performing important routine activities in a timely manner; and,
- *Focused reasoning*. The IAS must be able to control its reasoning such that it can achieve specific goals. The IAS will face more ‘problems’ than it can solve in real time, and so it is important that the IAS must be able to choose the most urgent problem(s) to solve first.

5.2.4.4 Real-time Performance

- *Guaranteed inter-operation latencies*. The IAS must be able to guarantee that it can achieve certain goals within the prescribed time frames;
- *Time-stress responsivity*. The IAS should be able to respond to increased pressure on time resources by decreasing its response latency;
- *Graceful degradation*. The IAS must be able to reduce response latency as a function of time stress by compromising precision and confidence in a graduated manner; and,
- *Speed-knowledge independence*. The IAS must be able to produce consistent response latencies despite the inclusion of new knowledge.

From these guidelines, it is evident that there are a number of obstacles in a real-time IAS providing outputs with guaranteed levels of completeness, timeliness, precision and confidence for a wide range of input states. However, a number of issues arise if these obstacles cannot be overcome by increasing the computing power available, or bounding the scope of the system’s operations (Hayes-Roth, 1991), including:

- What is the effect on the ability of the operator to make decisions based upon information of varying quality?;
- An operator may need to identify why the required level of accuracy could not be achieved as this information may affect future decisions; and

- The interface should provide as much information as possible about any problem that could not be solved, so that the operator can judge the best course of action in the situation.

5.3 Summary

Table 15 summarises issues relating to adaptive automation and interfaces, Table 16 summarises operator-system teamwork implications and supervisory control for Intelligent Adaptive Systems, and Table 17 provides a summary of goal/task based adaptive automation and dynamic learning systems.

Table 15: Summary of issues relating to Adaptive Automation and Adaptive Interfaces.

	Operator Training	Learning Systems (Dynamic Adaptation)	Information Presentation
What?	The operator should be on the features and functionality of the system.	The system learns (modifies its algorithms) from interactions with the operator.	The way information is presented to the operator and the layout of the OMI.
Debate	How much training is required. Novice vs expert training.	What are the criteria for system learning (i.e., operator behaviour?). Dynamic vs fixed implementation of adaptation.	How to structure the information and layout of the OMI. Best means to acquire requirements.
Why?	To ensure proper mental model of the system is acquired. Manage OOTL performance problems and workload. Operator acceptance. Particularly important in life-critical, mission-critical systems. There is a critical need for operators to understand and experience the potential benefits of adaptation. A hybrid adaptive OMI based on experience with the adaptive system is suggested to increase the operator's understanding of the system and its impact: a phase dependent mix between fully automatic and operator-controlled adaptation.	Powerful mean to adapt automation or UI to the individual. Support operator learning (of the system and the domain) and decision making. Support dynamic nature of complex environments (e.g., fast changing WWW; complex and dynamic military operators). Ensure that the system is "aware" of the world.	The OMI should present information that allows optimal performance when monitoring automation (e.g., multiple robots). The layout of the OMI should be based on operator requirements. EID can be used as a hierarchy tool to determine the structure of the OMI. An intelligent decision aid should support the level of experience and skill of the decision maker (e.g., present information according to experience level). Skill reduction in the operator. Failure of the operator to attend to important situational cues. UI should be predictable to support operator trust and promote rapid learning.
Reference	Kaber, Wright, Prinzel, & Clamann, (2005); Schneiderman and Maes (1997); Hou, M. Kobierski, R., Herdman, C. (2006)	Miller, C.A., Dorneich, M.C. (2006); Oppermann, Rashev, & Kinshuk. (1997); Roberts (2006); Schneiderman and Maes (1997); Hou, M. Kobierski, R., Herdman, C. (2006)	Kirlik, Markert, & Kossack. (1992); Hou, M. Kobierski, R., Herdman, C. (2006)

	Authority (i.e., Control)	Allocation of Task/Function	OOTL performance problems
What?	Who, the operator or the system, should have authority of initiation of the adaptation. There are currently two main philosophies: the operator should "supervise and delegate" adaptation or that the authority could be shared among the operator and the system. The amount of operator control and involvement (adaptivity and automation) and the roles that humans and machines engage in or are in control over (i.e., information processing) should be considered in the design of a system.	The allocation of automated tasks (to the operator or the agent) at particular stages/roles based on task/function and context.	The inability to intervene or assume the task or role that the automatic system was responsible for at the time. When the operator is kept out-of-the-loop they are slower at detecting errors, less likely to be able to intervene, lose skills that were previously completed manually, and are unable to fully understand the systems' status.
Debate	How much each agent should have control and at what stage? Who makes that decision? Should operators always be in control?	What is the best strategy to determine which agent should perform the task / function?	Balance between workload and OOTL performance problems. How much of this balance relies on operator control of the system.
Why?	Keep operator in the loop. Operator acceptance. Trust. Cultural aspects. Safety. There is a spectrum of operator control over the adaptation of a system. Need a balance between workload and human OOTL performance problems. Operator control can lead to better perceived performance and higher overall satisfaction.	Knowledge of the task context and its associated information needs can help in the development of overall system. Implementation of adaptation. Managing task demand. Increasing operator performance. Automated information acquisition, analysis and action implementation can help reduce workload and increase performance in ATC tasks. Adaptive allocation could produce positive benefits to a wide range of pilot functions including task prioritization, mission segmenting, task initiation and cessation, risk identification, and workload management.	It is critical that the system informs the operator of any changes on the interface. Lack of proper training. Lack of operator control.
Reference	Miller & Dorneich (2006); Albery & Khomenko (2002); Oppermann, Rashev, & Kinshuk. (1997); Roberts (2006); Kaber,	Miller & Dorneich (2006); Kaber, Wright, Prinzel, & Clamann, (2005); Scallen, & Hancock, (2001).	Roberts (2006); Kaber, Wright, Prinzel, & Clamann, (2005); Hou, M. Kobierski, R., Herdman, C. (2006);

	Authority (i.e., Control)	Allocation of Task/Function	OOTL performance problems
	Wright, Prinzel, & Clamann, (2005); Findlater, L., & McGrenere, J. (2004); Kirlik, Markert, & Kossack. (1992).		Findlater, L., & McGrenere, J. (2004).

	Communication and Interaction
What?	How agents (operators and systems) communication and interact.
Debate	Should agents (operators and systems; systems and systems) communication as humans do?
Why?	Direct interaction with an agent (e.g., paperplip) can increase situational awareness and develop better mental model of the system. Adherence to an accepted but frequently implicit code of behaviour between individuals in any social setting may also play a key role in human-computer relations. For instance, don't assume every operator is the same; the machine should be sensitive and adapt to individual, cultural, social, and contextual differences. Good 'etiquette' are social mores that apply to people may also apply to intelligent machines. This can improve human-machine communication and therefore potentially enhance system performance. Personality in the collaborative computer agents may enhance human performance within a supervisory control task. Operators (especially extrovert operators) may feel stronger social presence when they hear a computer voice manifesting a personality similar to their own than when the voice did not match their personality, even when the voices were clearly synthetic (similarity effect). Both of the experiments showed that a voice suggesting an extrovert personality induced a greater sense of social presence than a voice that sounded like an introvert. While still an open question, current research suggests that humans have an automatic tendency to be very liberal in assigning humanity to an artificial stimulus as long as they have at least minimal human features and if follow a social rule governing human-to-human interaction. Direct communication with an agent through an interface can be an effective means of human-machine communication. One must use anthropomorphic representation (e.g., Microsoft's paper clip) with caution: it may mislead the designers, and deceive operators; it may interfere with predictability, reduce operator control, and undermines operators' responsibility. An "invisible" or transparent agent may be more effective. Direct manipulation designs promote rapid learning. It supports rapid performance and low error rates while supporting exploratory usage in positive ways. Eye movement data might offer valuable information relevant to the utility of life-like agents. The tracking of eye movements can capture the operator's interaction with the system in real time, which is hard to do using post-experiment questionnaires.
Reference	Armentano, Godoya,& Amandi. (2006); Sheridan, & Parasuraman. (2006); Lee & Nass. (2003); Gallimore & Prabhala. (2006); Sofge, D., Bugajska, M., Adams, W., Perzanowski & Schultz. (2003); Schneiderman and Maes (1997); Prendinger, Ma & Ishizuka (2007)

Table 16: Summary of operator-system teamwork implications and supervisory control for Intelligent Adaptive Systems.

OPERATOR-SYSTEM TEAMWORK IMPLICATIONS			
	Authority (i.e., Control)	**Allocation of Task/Function**	**Applicability**
Issues	In team coordination, effective authority coordination requires that cooperating team to team members should know as much as possible from each other's performance characteristics and behavioral traits. The actual adjustment of an agent's level of autonomy could be initiated either by a human, an agent, or some third party. A system in which the machine learner and human operator more equally share responsibility can guide the learning process.	Bayesian Belief Networks can be used to structure task allocation, task sharing, team composition, procedures and OMIs from a teamwork perspective Must be careful of "clumsy automation": the erroneous notion that automation activities simply can be substituted for human activities without otherwise affecting the operation of the system. Humans also need to be able to control and re-direct the software agents as task requirements change.	Teamwork concepts should be considered when designing systems that require human operators to simultaneously control several functions at various working positions, such as controlling multiple UAVs. To ensure that interactions between agents and people are as natural and effective as possible The more the system understands its operators and their tasks, the more useful it will be for them. *Human-machine cooperation* can be achieved by allowing an operator, in executing her part of a plan, to expect a system to help in executing part of the plan. A *plan* is a set of processes (often to be executed by a number of different agents) that when run together successfully, accomplish some goal. Plans attempt to express a common understanding of how an operator and a system interact. A mixed-initiative framework in which the learner and human operator are each participants in a dialogue could improve the learner's hypothesis with minimal effort on the part of the operator. A systems needs to support multiple facets of individual cognitive and collaborative work.
Reference	Onken (2002); Wolfman, Lau Pedro Domingos, & Weld. (2001);	de Reus, Roessingh, & Pouw (2006); Eggleston, Roth, Scott. (2003);	de Reus, Roessingh, & Pouw (2006); Franklin, Budzik, & Hammond. (2002).; Wolfman, Lau Pedro Domingos, & Weld. (2001); Eggleston, Roth, Scott. (2003);

	Situation Awareness
Issues	Each actor, both human and agent, must be able to realistically assess the overall situation and current the state and intentions of the other team members. The system should always tries to understand the operator's actions in the context of what it believes the operator is doing. Automated agents need to be observable (or transparent/visible) so that operators are able to see what the automated agents are doing and understand what they will do next relative to the state of the task. How much "visibility" needed is questionable (i.e., not at all but then issue of trust and mistrust can occur or fully visible such as the Microsoft "PaperClip" which takes advantage of assistant and subordinate metaphors)
Reference	Franklin, Budzik, & Hammond. (2002); Eggleston, Roth, Scott. (2003);

SUPERVISORY CONTROL IMPLICATIONS			
	Authority (i.e., Control)	**Allocation of Task/Function**	**Applicability**
Issues	The tasking interface allows the operator to inspect and interact with the task model by extending the operator's ability to "call plays" and activating tasks at various levels of decomposition (e.g., Playbook). Teaching the operator to become an *effective supervisor*. *Levels of Authority*: full, inform, override, approval, recommend, monitor, none. The *Level of Aggregation* identifies how much (and/or which type) of resource each actor is authorized to use.	Tasked systems are always sub-ordinate, but know enough about the tasks in the domain that instructing them is vastly easier than instructing traditional automated systems. *Level of Abstraction.* Automation can have responsibility for higher- or lower-level tasks within the task hierarchy.	Enabling a system to behave more like an intelligent subordinate, operators may be more tolerant of their weaknesses and acceptable of their capabilities in a controlled setting (operator acceptance). Requires more direct interaction with the tasking interface. Slightly higher workload when participants had flexible access to both manual control and automated plays. Train the human to adequately supervise the system functioning. A question is how to control the delegated system. Not all of three (level of authority, abstraction and aggregation) dimensions may be available or relevant to every system or every interaction, but the model needs to be rich enough to encompass them.

Reference	Miller & Goldman (1999); Breton & Bosse, E. (2002); Miller, C. (2005).	Miller & Goldman, R. (1999); Miller, C. (2005).	Miller & Goldman (1999); Parasuraman & Miller (2006); Breton & Bosse, E. (2002); Miller, C. (2005).
	Situation Awareness		
Issues	A supervisor role can be an effective balancing technique between reducing mental workload, attentional demands, the effect of fatigue and stress factors and the probability of errors and maintaining situational awareness. These interfaces allow operators to respond effectively to unpredictable changes and which was associated with the flexibility afforded by delegation interfaces.		
Reference	Parasuraman & Miller (2006); Breton & Bosse, E. (2002);		

Table 17: Summary of Goal/Task-based Adaptive Automation and Dynamic Learning Systems

	Goal/Task-based Adaptive Automation	Dynamic Learning Systems
Advantages	Modelling techniques can be implemented offline (and no real-time criticality issues) and easily incorporated into a rule-based expert system. Pre-defined rules and critical events triggers can be combined with other implementation methods (e.g., the level or type of automation is changed based on an assessment of operator state) for a best general approach. The operator can specify pre-defined goals for the automated planning system. Goal/Task-Based systems can allow agents to dynamically and flexibly assume a range of roles depending on the task to be performed and the current situation.	Can provide a variety of rich interaction modes that enhance the learning process on the part of the operator and the system. The operator can control the next stage of discourse, updating the state of the learner which can then be rescored based on the new state of the learner (operator). A system based on experience with the adaptive system can increase the operator's understanding of the system and its impact. As the system learns from its interaction with the operator's past behaviour, the system can provide more accurate and timely adaptation (see StockTrader). The ability to reason about the activity of an operator is crucial to the implementation of an intelligent OMI. The pre-defined user model may not apply to all operators (e.g., different usage patterns), and therefore a learning system can dynamically adapt based on a usage pattern or interactivity with the system. The more the system understands its operators and their tasks, the more useful it will be for them. Compensate for individual characteristics.
Disadvantages	Valid model is required and different models within the same system might give contrary decisions at particular moments. Potential for complex implementation: multiple processes (agents) and operational knowledge representations (frameworks) are necessary for complex IAS interactions. The initiation of automation (i.e., allocation of task to a system) must be sensitive to the operator's combined tasking environment, which depends on interactions among tasks, the environment and the operator state (e.g., workload).	Potential for poor user models. Potential for complex implementation of agents.
Relationship to Frameworks	COGPIT; RA/RPA; Playbook; CAMA; Co-Pilot Electronique; SAWA; Work-Centered Decision Support; CASSY; DRDC UAV Project.	Intelligent Classroom; DIAManD; StockTrader; Lookout; Personal Web Server.

6 Operator-State Monitoring Approaches

6.1 Introduction

An operator is a critical determinant that influences the behaviour of a war-fighting system. Any minor errors, lapses of attention or losses of Situation Awareness can quickly onset disastrous consequences. For this reason, the ability to make inferences about current operator state is a critical requirement for effective system management. Such inferences would provide information about current operator-state, but could also signal possible problems at later times or for specific future tasks. For example, detection of the onset of drowsiness and fatigue might prevent serious problems at a later stage. Similarly, recognition that the operator is already working at or close to maximum potential serves to warn that the imposition of further load may lead to impaired performance. A number of systems (e.g., Cognition Monitor component of the Cognitive Cockpit) have been designed to supply the type of information that enables these inferences to be made. Critically, they have been designed to perform these functions in real time.

6.2 General Characteristics of Operator-State Monitoring Systems

Operator state is a general term that is used to characterise the overall condition of an operator at any particular time. It refers to a combination of behavioural activity, physiological patterns and subjective states, and is strongly context-dependent. In considering the operator as an agent within a complex system, the term ‘operator state’ is preferable to more specific concepts such as workload (Pleydell-Pearce, 1999). The use of operator state is preferred lapses of attention, losses of awareness, or the production of errors are not necessarily restricted to periods of high workload. Thus, in attempting to characterise operator state, measurement of workload is only one of the functions of operator state assessment technologies.

Inferences about operator state can be derived from four principal sources, either used individually or in combination: behavioural measures; physiological measures; subjective measures; and through a consideration of contextual information. Overall, this feedback provides information about the objective and subjective state of an operator within a mission context. This information then provides a basis for the intelligent adaptation of the interface to best support the operator.

Sections 11.3 through 11.5 review the technologies for designing behaviour-based and physiological based interface systems, and compare the differences between behaviour-based and physiological-based techniques and the benefits of combining the two techniques.

Reference:

Young. P.M., Clegg, B.A., and Smith, C.A.P. (2004). Dynamics models of augmented cognition. International Journal of Human-Computer Interaction, 17(2), 259-273.

Overview:

This paper discusses modeling based on an engineering control systems theory and offers insights into closed-loop systems; that is, real-time cognitive state detection. Controls system theory deals with the fundamental properties of systems described by mathematical models. Note that these mathematical models were out of the scope of this review; therefore, please refer to the article for further information regarding the implementation of the mathematical models.

A closed-loop dynamic model entails taking a measurement of cognitive workload (e.g., neurological and physiological measures) and using that to adapt the operator's input. This model required a cognitive workload and action model.

It was shown that dynamic instability (that is, reliable input to the operator) can result from introducing feedback within a system. That is, rapid detection of a cognitive state under high workload might result in input being removed, which would reduce the workload and hence, additional information is provided (e.g., cluttered display) which would again result in high workload, etc. The authors provide some methods that can be applied to remove such instability and optimise performance.

Conclusions for IASs:

1. A control systems model incorporating the flow of human information processing (Perception, Decide, Respond) can be used to determine mathematical operations (performance properties of the system).
2. A closed-loop approach can be used to examine the application of sensors to measure cognitive states and to enhance human performance, and vice versa, even before they physically exist.
3. It is important to understand the affects of feedback on a closed-loop system (e.g., stability, tracking and performance, noise and disturbance rejection, and bandwidth).
4. It is important to systematically examine the effects of optimized human performance measures in regards to the stability of the input.

Reference:

Prinzel, L.J., Freeman, F.G., Scerbo, M.W., Mikulka, P.J. and Pope, A.T. (1999). A Closed Loop System for Examining Psychophysiological Measures for Adaptive Task Allocation. The International Journal Of Aviation Psychology, 10(4), 393–410.

Overview:

This paper discusses a study that examined the effectiveness of a closed-loop system to moderate an operator's level of engagement where the automation was driven by the operator's own EEG. The study also examined the impact of different task loads on adaptive task allocation and system regulation of task engagement and workload.

The use of physiological measures in this study is based on the concept that an optimal state of engagement exists. It is thought that changes in arousal and resource capacity are controlled by feedback from other ongoing activities. For instance, an increase in the task load can enhance arousal and decrease resources.

Pope et al (1995) developed an adaptive system that uses *a closed-loop procedure* to adjust the mode of automation based on changes in an operator's EEG patterns. The closed-loop method was developed to determine optimal task allocation using an EEG-based index of engagement or arousal. The system uses a biocybernetic loop that is formed by changing levels of automation in response to changes in mental workload demands. Thus, an inverse relation exists between the level of automation in the tasks and the level of operator workload. The study applied this closed-loop system to moderate the operator's level of engagement and apply automation.

Study results showed that performance in the experimental group was significantly improved compared to the control group.

Conclusions for IASs:

1. Results from this study suggest that the closed-loop system can facilitate performance.
2. A closed-loop feedback system can provide a method for regulating operator attention, arousal, and workload, and represents a method for the use of psychophysiological measures in adaptive automation technology.

6.3 Behavioural-based Monitoring

6.3.1 Behavioural Measures

Measurement of the overt physical behaviour of the operator can provide a rich database that can form the basis for inferences concerning the current state of the operator. For example, if an operator is engaged in a conversation with another party, this indicates that the verbal systems within the operator's brain will be heavily committed to that channel, and the facility to deal with or act upon other verbal tasks may be diminished. This inference is based upon well-documented problems associated with parallel processing of multiple streams of verbal information. Alternatively, if a particular system is currently being manipulated, this permits inferences about the current focus of attention, and provides some idea about current cognition and intention. Furthermore, sensors that track head and eye position can provide information about the current locus of visual fixation that enables inferences about the locus of visual attention. Combinations of such behavioural measures can provide information about time-sharing and dual-task performance. Finally, inferences can be made about operator cognitive state using a pre-existing knowledge base in which the functional significance, and cognitive implications, of system controls are represented. In this way, behavioural monitoring is able to provide some degree of inferences about operator intent.

6.3.2 Subjective Measures

Subjective measures of operator state are those provided by the operator. In conventional settings these are often paper and pencil tasks (e.g., NASA TLX). However, the collection of such data can be easily automated; for example, there could be provision for the operator to signal subjective states (i.e., the operator's perception of their current level of workload) that may be of concern. For example, states of very high workload where performance may be deteriorating can be signalled using speech or a single button press. Similarly, the recognition of chronic under-arousal, and the realisation that sleep onset can also be communicated. Under conditions of more-manageable workload, the operator can also signal task elements that are experienced as overly demanding. These forms of subjective data are invaluable indices of operator state. Incorporating such measures within a closed-loop system directly links the operator with the on-board monitoring systems, and as a result, keeps the operator 'in-the-loop'.

6.3.3 Contextual Measures

Context provides information that enables interpretation of changes in behavioural, physiological and subjective measures. For example, aircraft take-off and landing are associated with dramatic changes in physiological variables such as heart rate.

Inferences made about operator state can therefore be enhanced by information about general contextual factors. Furthermore, since effects of context on performance may be predictable, this allows inferences about the impact of that context on overall operator state. In order to achieve this, the operator state monitoring system must collect low-level contextual information (e.g., ambient noise, luminance and temperature, which are all factors known to influence performance).

<u>Reference</u>:

Wood, S. (2006). Automated behavior-based interaction customization for military command and control. Technical Report.

<u>Overview:</u>

This paper proposes an intelligent control framework (ICF), for behaviour-based customization of an adaptable system. The authors propose that this framework, while developed to automate and assist with warfighter tasks, can also be applied generically to any adaptive interface.

Adjustable Autonomy Module. This module is a component of IFC that dynamically allocates tasks by using a combination of behavior recognition, modeling, and reasoning tools. The module performs the following operations:

1) Senses external and operator stimuli;
2) Recognizes new tasks and monitors the progression of existing tasks;
3) Simulates operator actions to determine information and other task needs;
4) Updates the operator and situation models;

5) Determines automation levels, and,
6) Updates the instructions for control over automation.

Intelligent Control Framework. Inputs from the operator, system status information, and external events are used as inputs to the system. As output, the system produces a model that includes the operator's current situation, and a table of adjustable autonomy and data on the current tasks with associated autonomy levels. The autonomy levels indicate which tasks the system should be engaged in at any point in time, to what degree the system hould be performing or monitoring those tasks, and links the tasks back to information in the user model.

Conclusions for IASs:

1. Design of the adjustable autonomy module architecture raised several scientific and engineering issues, which are issues critical within any application of behavior-based customization:
    a. How does behavior-based customization fit within a larger control hierarchy/system?
    b. Since operators rarely perform one action at a time, how best can individual operator actions be interpreted and assessed with regard to current or new tasks? How can task progress be accurately measured? How can an operator deal with canceled, intermittent, or suspended tasks?
    c. How must these traditional modeling techniques be augmented to adequately deal with expected world events, task priorities, operator information needs, etc., and use that additional information to more accurately recognize operator action plans?
    d. How must these underlying technologies be redesigned to enable smooth transition from operator control to system control without creating an undue mental context-switching cost on the operator?
    e. How will operators interact with the system for maximal benefit?

Reference:

Alpert, S. R., Karat, J., Karat, C. M., Brodie C., & Vergo, J. G. (2003). User attitudes regarding a user-adaptive e-commerce web site. User Modeling and User-Adapted Interaction 13(4), pp. 373-396.

Overview:

A study to evaluate operator attitudes towards an adaptive UI for an eCommerce Web site based on explicit and implicit operator model was conducted. The implicit user model (behaviour) is based on previous navigation with the interface. The explicit model is based on direct feedback from the operator.

Conclusions for IASs:

1. Results show that operators wanted explicit control of their operator profiles due to trust issues. Wanting this sense of control was partially related to whether the participant could readily make sense of the interaction with a web site (i.e., have a proper mental model of system functioning).
2. Participants reported that they were happy with adaptive content based on information

explicitly provided by them, but were mixed in their reactions to adaptivity, based on implicit information.

3. Operators expected the system to respond to the ongoing dialog, and to be as informative as only required.
4. A highly rated feature was “content filtering” based on explicit information provided by the operator or explicitly selected by the operator, or information which is explicitly accessible in the operator’s profile.
5. An explicit user model can help operators develop a mental model of the system; that is, operators obviously understand the causal relationships that give rise to the content. When immediate context is used to guide content, operators can easily infer the source of the site’s content. Workload increases however with an explicit user model.

Reference:

Bonner, M.C., Taylor, R. M., Fletcher, K., and Miller, C. (2000). Adaptive automation and decision aiding in the military fast-jet domain. *In proceedings of the conference on Human Performance, Situation Awareness and Automation: User centred design for the new Millennium*.

Overview:

This paper presents the operation and technical development of the Tasking Interface Manager component of the Cognitive Cockpit. The TIM utilised input from the Situation Assessment Support System and the Cognition Monitor to adaptively present information and adaptively automate tasks according to the situational context and a pilot's internal state. The goal of TIM is to reduce aircrew task and cognitive load. The main feature of the TIM is a shared mental model, the ability to track goals, plans and tasks, and the ability to communicate intent about the mission plan. The objective of the TIM is to allow aircrew to retain executive control of aircraft and mission parameters in conjunction with the assistance of adaptive automation.

Conclusions for IASs:

1. To maintain operator situational awareness, tasks should be tracked explicitly (e.g., by asking the operator for input or by making the system state visible to the operator), especially in high-criticality environments.

Reference:

Gerlach, M. and Onken, R. (1995). CASSY - The electronic part of the human-electronic crew. Proceedings of the 3rd international workshop on human-computer teamwork (Human-Electronic Crew: Can we trust the team?). Cambridge, UK, 27-30 September 1994.

Overview:

The knowledge-based commercial aircraft Cockpit Assistant System is a civil aviation cockpit assistant project developed as an intelligent decision aid. It emphasises pilot assistance through situation assessment and re-planning in flight. Situation-dependent assistance with flight planning is guided by a normative pilot model, goal conflict, pilot intent, and error recognition functions. It also aids in the execution of pilot selected functions.

CASSY is composed of several situation assessment modules that interface with the flight crew, the aircraft, and air traffic control, which all collaborate with each other The CASSY project is a successful real-time demonstration of an intelligent adaptive system implemented in a real and not virtual environment. This project led to the CAMMA military cockpit assistant project.

Conclusions for IASs:

1. Flight tests proved that intelligent decision aiding is feasibly possible, and well accepted by operators.
2. Situation assessment is an important feature of a successful intelligent system.

Reference:

Wittig, T. and Onken, R. (1992). Pilot intent and error recognition as part of a knowledge based cockpit assistant. Proceedings of the AGARD conference on Combat automation for airborne weapon systems: Man/machine interface trends and technologies, Edinburgh, UK, 19-22 October 1992.

Overview:

This paper describes the concept and functionality of the Cockpit Assistant System (CASSY); including pilot intent and error recognition. Evaluation of CASSY in a flight simulator is also described.

Conclusions for IASs:

1. Operator intent and error recognition can be an effective means of providing adaptive assistance.
2. Uncertainties can be evaluated using certainty factors (probabilistic reasoning such as Bayes' Theorem).
3. Algorithms based on a-priori probabilities for possible hypotheses have proven useful for recognizing and estimating operator intent. The probabilities can be modified with respect to operator actions.

6.4 Psychophysiological-based Monitoring

6.4.1 Physiological Measures

Although behavioural measures are clearly useful, they by no means provide a full and definitive picture. For example, a response in itself may provide no information about current levels of arousal and alertness. Furthermore, research over the last decade has indicated that changes in cognitive load have predictable effects upon physiological measures, particularly those occurring within the brain. This means that physiological measures can provide an objective and non-invasive index of load imposed upon distinct brain systems that have specific functions. A number of physiological variables that can provide such an index of cognitive load are described in Sections 11.4.1.1 through 11.4.1.8.

6.4.1.1 Electroencephalographic Measures

Sensors placed in contact with the scalp are able to detect electrical changes within the brain. Although these voltages are small, they can be measured when the signals are passed through high-gain amplifiers. These measures of EEG activity are closely associated with behavioural state (e.g., under and over-arousal, high-order cognition, modality-specific processing, verbal and spatial processing, etc.). Most measures of EEG activity are in a bandwidth lying between 0 and 400Hz at widespread regions across the scalp. They are able to make inferences about activity in functionally specific regions of the brain (e.g., visual, auditory, somatosensory and frontal executive regions), and also provide an index of both drowsiness and alertness using changes in the power of particular frequencies (e.g., delta, theta, alpha, beta and gamma). A problem with interpreting EEG, stems from the fact that individual brains may differ in organisation, and that different strategies and styles are associated with distinct patterns of EEG activity. Another problem associated with EEG recording is that eye-movements and blinks produce far-field potentials which are detected by scalp electrodes.

6.4.1.1.1 Electro-oculographic (EOG) Measures

Electrodes placed above and below an eye are able to detect eye-movements, and signal the occurrence of blinks. These sensors do not impede normal vision. EOG measures of eye-movements can provide extremely accurate measures of fixation under ideal conditions. Blink rate has been demonstrated to correlate with visual workload; blink rate reduces when visual workload increases. Increased blink frequency, and longer duration blinks have also been related to fatigue and the onset of sleep. Saccade rate provides an index of visual scan rate, and provides an approximate measure of visual shifts.

6.4.1.2 Electrodermal Activity

Electrodermal activity at the skin surface has been used as a measure of autonomic activity for many decades. Although numerous systems have been used, most measure changes in skin impedance/resistance. Electrodermal activity is measured using a small sensor array attached to the skin. Changes primarily arise as a result of alterations in sweat gland activity; increased sweat gland activity indicates increased autonomic arousal. While electrodermal changes do not provide a direct measure of higher level cognition, they do indicate increments and reductions of arousal and stress reactions. This is important, as research over several decades has shown that excessive increments in autonomic arousal are associated with dysfunctional attentional narrowing, distraction by irrelevant inputs, and marked impairments in cognitive task performance.

6.4.1.3 Heart Rate and Heart Rate Variability

Increments in load have been shown to be accompanied by systematic changes in cardiac activity. A simple measure of cardiac activity is supplied by heart rate, expressed in beats per minute. Increments in workload have been associated with increased heart rate. Inter-beat interval has also been found to correlate with changes in workload. These measures are derived from ECG electrodes placed in contact with the skin.

6.4.1.4 Respiration Measures

Measures of respiration (e.g., breathing rate) are indicative of operator state; shallower and higher frequency patterns of respiration have been shown to be associated with increments in stress and cognitive demand, and respiration rate exerts significant effects upon heart rate and heart rate variability. Thus, frequency decomposition of the respiratory cycle enables an assessment of the degree to which cardiac changes are artefacts of respiratory variability. Respiration rate can be measured using a strain gauge or the “dolls eye” located within aircraft respiratory systems.

6.4.1.5 Skin Temperature Measures

Variations in skin temperature have also been related to changes in autonomic activity; increased activity in the sympathetic nervous system results in vasoconstriction of peripheral arteries which lowers skin temperature at bodily extremities. For this reason, decrements in peripheral temperature have been used as measures of stress and arousal.

6.4.1.6 Electromyographic Measures (EMG)

Electrodes attached to skin are sensitive to activity in underlying muscle groups. Muscle activity is predominantly associated with frequencies in the range of 10Hz and upwards and is particularly marked between 50Hz and 150Hz. Such measures are indicative of effector workload and more physically onerous acts are associated with higher amplitude EMG activity. This means that alterations in peripheral load associated with control of devices, such as joysticks, can be mapped in real time. EMG measures also correlate with state variables such as drowsiness. Indeed during drowsiness, sleep onset and sleep itself, there is a progressive decrease in muscle activity. Thus a decrease in muscle tonus may indicate dangerously low levels of alertness. In contrast, states of higher arousal are associated with increasing muscle tonus.

6.4.1.7 Vocalisation and Auditory Communication Detection Systems

A major source of workload stems from the requirement of operators to use verbal communication. This includes using speech recognition software to interact with the system and communication with other operators and remote stations. There are two techniques to measure vocalisation and auditory communication; the first technique measures vocalisation via electrodes attached at the skin surface around the larynx, and the second technique uses analog to digital conversion and frequency analysis of information passing through pilot microphones. The second technique is advantageous as it is simple and non-invasive. When the system detects vocalisation, it infers that the operator is paying attention to verbal information, indicating that additional verbal load in any modality is likely to be processed less effectively.

6.4.1.8 Ambient Sensors

Operator state monitoring systems also make use of a number of sensors providing information about ambient factors. These include ambient noise, since increments in noise are known to influence performance, and ambient temperature and luminance, since the extremes of both these measures have well documented and deleterious effects on performance.

<u>Reference</u>:

Parasuraman, R. (2003). Neuroergonomics: research and practice. Theoretical Issues in Ergonomics. Science, 4 (1–2), 5–20.

<u>Overview:</u>

This article describes the characteristics and scope of neuroergonomics. This is defined as the study of brain and behaviour.

The author details the advantages and disadvantages of *Neuroergonomics.* Neuroergonomics investigates the neural bases of various perceptual and cognitive functions (such as seeing, hearing, attending, remembering, deciding and planning) in relation to technologies and settings in the real world. The basic principle of neuroergonomics is to understand how the brain works to perform various tasks. A core feature of neuroergonomics is an interest in brain mechanisms in relation to human performance at work.

Neuroergonomics has two major goals when looking for links between brain function and the world of technology and work. The first is to design technologies by using existing and emerging knowledge of human performance and brain function. The second goal is to enhance our understanding of brain function in relation to human performance in real-world tasks.

Neuroergonomic measures offer new ways to understand how to implement adaptation. For instance, changes in reaction time may reflect contributions of both central processing (working memory) and response-related processing to workload. However, when coupled with the amplitude and latency of the P300 component of the ERP, such changes may be more precisely localized to central processing stages than to response-related processing. In addition, measures of brain function can indicate not only when an operator is overloaded, drowsy, or fatigued, but also which brain networks and circuits may be affected.

Below outlines the benefits and costs of various neurophysiological measures for adaptive automation and understanding of brain function in relation to human performance.

<u>Conclusions for IASs:</u>

1. *Brain imaging techniques*. Offer the most direct measure of brain functioning. Examples include EEG, MEG, ERPs, MRI, fMRI, TMS. These techniques can be expensive and restrict movement but new technologies are becoming cheaper and more portable.
2. PET and fMRI measures of brain activity, as well as electromagnetic measures such as EEG and ERPs, provide sensitive indexes of moment-to-moment variations in mental workload in adaptive human–machine systems.
3. Transcranial Doppler sonography (TCD) has high temporal resolution, thus allowing for

continuous, real-time monitoring of cerebral blood flow.

4. Physiological measures recorded from the body (e.g., heart rate, skin conductance, urinary catecholamines, blood pressure, etc.) focus on autonomic nervous system (ANS) measures in relation to somatic factors, emotion and stress.
5. Neuroergonomics and psychophysiology in ergonomics share a common goal of seeking the design of safe and efficient human–machine systems. The two can be considered complementary and overlapping approaches.
6. Physiological measures may be recorded continuously without overt responses and may provide a measure of the covert activities of the human operator.
7. In some instances, measures of brain function may provide more information when coupled with behavioural measures than using behavioural measures alone.
8. Physiological measures can possibly predict *human error* by analysis of brain activity that has been previously associated with errors. For instance, a specific ERP component associated with errors has been identified, the error-related negativity (ERN). Errors made in a choice reaction time task in which either the hand or the foot was used to respond led to nearly identical ERN.
9. Analysis of learning a complex task can be completed by understanding the brain changes that accompany stages of learning. This could lead to the development of better training procedures. PET and fMRIs can be used for short and long term studies of learning.
10. Other applications. *brain-machine interface* (controlling external devices with brain potentials) and understanding mechanisms of *spatial navigation* could have important implications for further understanding of the mechanisms of spatial navigation and its acquisition in expert groups, such as pilots and controllers.

Reference:

Russell, C.A. (2005). Operator State Estimation for Adaptive Aiding in Uninhabited Combat Air Vehicles, Dissertation (Report No. AFIT/DS/ENG/05-01). Air Force Institute Of Technology, Wright-Patterson Air Force Base, Ohio.

Overview:

This document is a dissertation that describes a series of experiments to examine the effectiveness of a closed-loop system, based on an operator's cognitive functional state, to adaptively aid in UCAV (Uninhabited Combat Air Vehicle) operations. Specifically, it examined how this closed-loop system can help deal with high workload situations without disengaging the operator from the task.

Adaptive aiding was implemented based on "operator state estimation" whereby the system adapts when the operator is cognitively loaded.

The operator functional state was determined by integrating and assessing multiple psychophysiological measures using an operator state classification system. That system was then used to change the environment.

Operator state has four major components: psychophysiological assessment (cognitive workload); operator performance assessment; situation awareness assessment; and momentary mission requirements. The primary focus in this research is closing the loop' of the human-machine system based on cognitive workload alone.

The author reports on studies which suggest that EEG measures can be used to determine multiple levels of cognitive load in complex tasks. EEG measures are sensitive to cognitive differences and reliable enough for consistent use. Artificial neural networks meanwhile have been used in both simple single-task laboratory and complex multiple-task studies to classify cognitive workload.

The integration of system adaptive automation and natural human adaptation must be accomplished to eliminate the possibility of human-system instability; operators themselves are adaptable and can respond to systems in unpredictable ways. This integration may be accomplished by adding psychophysiological measures to the existing system.

Conclusions for IASs:

1. Artificial neural networks (ANNs) have been successfully used to accurately classify cognitive workload (differences in EEG) in a variety of environments.
2. Adaptive aiding based on psychophysiological measures (i.e., EEG) can improve operator performance and increase mission effectiveness. This effectiveness however is dependent on providing aid at appropriate times. In this study, operators who were aided at random times had the same performance as unaided operators.
3. Result found that adaptive aiding through a closed-loop system improved operator performance and increased mission effectiveness by 67%.

Reference:

Wilson, G.F. (2002). Adaptive Aiding Implemented by Psychophysiologically Determined Operator Functional State. In Proceedings of RTO Human Factors and Medicine Panel (HFM) Symposium held in Warsaw, Poland, 7-9 October 2002.

Overview:

This paper provides examples for the application of psychophysiological measures (mental workload, fatigue, and inattention) to classify operator functional state (OFS).

The author reports on studies which evaluated various psychophysiolocial measures for adapting automation. These studies demonstrate that psychophysiological measures can provide high levels of accuracy in predicting changes in operator state. Correct classification of OFS accuracies range from 85% to 98%.

An example of this approach is using a stepwise discriminant analysis and artificial neural network classifiers to determine how well they could correctly classify the mental workload of operators.

Conclusions for IASs:

1. Psychophysiological measures can provide a more accurate estimate of OFS status to adapt the interface in real-time minimal interference.
2. The classification of OFS must be highly accurate in order to provide useful information.

3. The situation awareness (SA) of operators should be evaluated in light of the current mission requirements. The psychophysiological and SA evaluations could then be used to determine their functional state. The current mission requirements would provide the context with which to determine if the current OFS was appropriate or if adaptive aiding was required.

Reference:

St John, M., Kobus, D.A., and Morrison, J.G. (2003). DARPA Augmented Cognition Technical Integration Experiment (TIE). DARPA Technical Report 1905. December 2003.

Overview:

This paper describes the empirical results of a Technical Integration Experiment (TIE) involving the evaluation of 20 psychophysiologically derived measures (cognitive state gauges) that were developed under Phase I of the Augmented Cognition program. A key attribute of the TIE was the use of a common experimental test task, evaluated under comparable test conditions. This report attempts to examine the prospects for, and issues that must yet be addressed for, the successful transition of these cognitive state gauges to field-able military person-machine systems in Phase II of the Augmented Cognition program, and beyond.

The sensor technologies included functional Near Infra-Red imaging (fNIR), continuous and event-related electrical encephalography (EEG/ERP), eye tracking and pupil dilation, mouse pressure, body posture, heart rate, and galvanic skin response (GSR).

Refer to the report for details on the advantages and disadvantages of each gauge.

Conclusions for IASs:

1. When implementing psychophysiological gauges, there is a need to define and refine the meaning of each gauge and what it measures.
2. *Level of operator experience.* When evaluating a gauge, the system design needs to understand how operator skills and experience (including practice effects) can influence gauge performance.
3. *Operator acceptance.* To maximize the likelihood of operator acceptance, gauge hardware should be comfortable, mobile, convenient and as non-intrusive as possible, particularly in mobile environments.
4. Potential sources of electro-magnetic frequency (EMF) interference need to be understood and addressed.

Reference:

Prinzel, L.J., Freeman, F.G., Scerbo, M.W., Mikulka, P.J. and Pope, A.T. (1999). A Closed Loop System for Examining Psychophysiological Measures for Adaptive Task Allocation. The International Journal Of Aviation Psychology, 10(4), 393–410.

Overview:

This paper discusses a study that examined the effectiveness of a closed-loop system to moderate an operator's cognitive level of engagement in the task, where the automation was driven by the operator's own EEG. The study also examined how different task loads impact adaptive task allocation and system regulation of task engagement and workload.

Physiological measures were used in this study based on the idea that an optimal state of cognitive engagement in the task exists. Changes in arousal and resource capacity are thought to be controlled by feedback from other ongoing activities. For instance, an increase in the task load for activities can enhance arousal and decrease resources.

Pope et. Al., (1995) developed an adaptive system that uses *a closed-loop procedure* to adjust the mode of automation based on changes in the operator's EEG patterns. The closed-loop method was developed to determine optimal task allocation using an EEG-based index of engagement or arousal. The system uses a biocybernetic loop that is formed by changing levels of automation in response to changes in mental workload demands. Thus, an inverse relation exists between the level of automation in the tasks and the level of operator workload. The current study applied this closed-loop system to moderate the operator's level of engagement and apply automation.

Study results indicate that performance in the experimental group was significantly improved compared to the control group.

Conclusions for IASs:

1. The authors report that an advantage of biopsychometrics for adaptive systems is that measurements can be obtained continuously with little intrusion. Also, since obvious performance indices are difficult to achieve when operators interact with systems, there may be fewer opportunities to measure resource capacity.
2. Task allocation and psychophysiological data can complement each other to support adaptive task allocation.
3. Technology is still immature to make psychophysiological measures applicable outside the laboratory.

Reference:

Miller, C.A., and Dorneich, M.C. (2006). From Associate Systems to Augmented Cognition 25 Years of User Adaptation in High Criticality Systems. Poster presented at the Augmented Cognition conference, October 2006, San Francisco.

Overview:

In the 1980's, the U.S. Air Force initiated the development of a human-adaptive, information, and automation management technology known as the "Pilot's Associate".

PA, and all of the subsequent associate systems, consisted of an integrated suite of intelligent subsystems that were designed to share (among themselves and with the pilot) a common understanding of the mission, the current state of the world, the aircraft and the pilot. Associate systems were designed to use the shared knowledge to plan and suggest courses of action, and to adapt cockpit information displays and the behaviour of aircraft automation.

Please refer to the Frameworks Section 8.4.2.2 for more details on this paper.

Conclusions for IASs:

1. *Importance of co-development and progressive testing*: Development efforts and individual technologies should be co-developed and used in collaboration, which can help aid in the development of an overall system. For instance, the development of neurophysiological sensors or "meters", and other means of assessing operator state, and the development of methods for "augmenting" cognition through information display technologies need to be co-developed and evaluated in concert.
2. *Benefits of an explicit, integrative framework (task model).* Knowledge of the task context can help develop systems that manage task demand and increases operator performance.
3. Importance of learning, especially individuation. *Recording individual performance effects could serve to provide a powerful means of adapting system behaviour to the individual.*

Reference:

Prendinger, H., Ma, C., Ishizuka, M. (2007). Eye movements as indices for the utility of life-like interface agents: A pilot study. Interacting with Computers, 19, 281–292.

Overview:

This paper outlines a pilot study that compared three types of media: an animated agent, a text box, and speech only. Authors propose a different approach to evaluating animated agents, one that is based on eye movement behavior of operators interacting with the OMI. The operators do not manipulate the interface. The authors argue that operators merely watching a presentation interact, even involuntarily, with their eye movements.

Physiological signals as an evaluation method for OMIs and as an input modality: The eye movement data was analyzed for diagnostic use (as a means to examine the operator's attention to evaluate the usability of interfaces), and for interactive use (a system responds to the observed eye movements and can thus be seen as an input modality).

The investigation of eye movements revealed that deictic gestures by the agent are more effective in directing the attentional focus of subjects to relevant interface objects than the media used in the two control conditions, at a slight cost of distracting the operator from visual inspection of the object of reference. The results also demonstrate that the presence of an interface agent seemingly triggers natural and social interaction protocols of human operators.

Conclusions for IASs:

5. Physiological signals can be used as an evaluation method for OMIs and as an input modality.
6. Eye movement data might offer valuable information relevant to the utility of life-like agents.
7. The usability of interfaces can be assessed using eye movements.
8. The tracking of eye movements can capture an operator's interaction with the system in real time, which is hard to accomplish using post-experiment questionnaires.

Reference:

Prinzel, LJ., Parasuraman, R., Freeman, F.G., Scerbo, M, Mikulka., P.J., and Pope, A. (2003). Three Experiments Examining the Use of Electroencephalogram, Event-Related Potentials, and Heart-Rate Variability for Real- Time Human-Centered Adaptive Automation Design. Technical Report (No. NASA/TP-2003-212442).

Overview:

This paper describes on three experiments that examined the psychophysiological measures of event-related potentials, electroencephalogram, and heart-rate variability for real-time adaptive automation.

The authors base their closed-loop system on a theoretical framework proposed by Byrne and Parasuraman (1996). This framework is proposed for developing adaptive automation around psychophysiological measures. The use of physiological measures in adaptive systems is based on the assumption that there exists an optimal state of cognitive engagement in a particular task**.** Capacity and resource theories are central to this idea. These theories posit that a limited amount of resources exist that can be drawn upon when performing tasks. These resources are not directly observable, but instead are hypothetical constructs. Therefore, physiological measures can be used to index cognitive resources.

A *closed-loop system* can compliment task allocation. The operators may be better able to predict the “state” of system operation, develop control strategies, select appropriate actions, and interpret the effects of selected actions with appropriate feedback.

The results of the experiments confirm that these measures can be an effective tool for use in both a developmental and operational role for adaptive automation design.

Conclusions for IASs:

1. The use of psychophysiological measures in adaptive automation requires that such measures are capable of representing mental workload.
2. It has been proposed that physiological measures in adaptive systems could be used to keep the operator in an “optimal state of engagement”.
3. It has been reliably shown that event-related potentials accurately measure mental workload. ERP however is fairly intrusive and difficult to implement and requires considerable expertise to interpret the results.
4. Heart-rate variability (HRV) is not as intrusive or difficult to implement as ERP, and is easy to use and reliable. However, it does not have the same capability as the ERP in terms of its diagnosticity of information processing.
5. A closed-loop system represents a method for the use of psychophysiological measures in adaptive automation technology.
6. A disadvantage of physiologically-based adaptation is the efficacy of different adaptive algorithms and/or adaptive logic (similar to behaviour-based).
7. The technology for physiologically-based adaptation is not yet mature enough.
8. Presently, there is not enough existing psychophysiological research to provide adequate

information on which to base the decision for adaptation.

9. It is suggested that psychophysiological measures could be used not only as an input signal for the regulation of automation, but also to assess underlying changes accompanying performance changes during development of adaptive automation systems.

6.5 Combination-based (Convergent) Monitoring

The previous sections indicate that operator state monitoring systems are able to capture and process a large amount of data. Although the various forms of data can be treated as separate variables, the relationships between different data sources also contain valuable information. For example, the absence of an arousal reaction to a mild threat, such as a low altitude warning, may indicate that the operator is confident and in control. However, it may also indicate a loss of SA caused by dangerously low levels of arousal. In recognition of the importance of *convergent* processing, combination-based adaptation systems are capable of performing complex multivariate analyses in order to improve inferences about operator state. A further benefit of convergent processing is that hidden predictive trends can often be discovered in the relations between data sets that cannot be obtained from either data set alone. Artificial neural networks can also be used in order to search for hidden patterns within data (Pleydell-Pearce, 1999).

A characteristic feature of human behaviour is that there are widespread differences in behavioural and physiological responses to similar situations. This means that conclusions that are based upon average findings from a group of individuals may correlate only weakly with the behaviour of a particular person. However, scientific approaches to problems such as mental workload are nearly always based upon data averaged across subjects. In contrast, very little research has attempted to identify unique but reproducible changes within single individuals. A major and novel feature of contemporary combination-based monitoring approaches (e.g., the Cognition Monitor of the Cognitive Cockpit) is that the monitoring system can learn about the behaviour of individuals, and look for predictable regularities in their response to changing patterns of workload (Pleydell-Pearce, 1999).

Reference:

Duric, Z., Gray, W.D., Heishman, R., Li, F., Rosenfeld, A., Schoelles, M.J., Schunn. C., and Wechsler, H. (2002). Integrating perceptual and cognitive modeling for adaptive and intelligent human-computer interaction. In *Proceedings of the IEEE, 90*(7), 1272-1289.

Overview:

The purpose of this paper was to describe technology and tools based on human cognitive, perceptual, motor, and affective factors, which are modeled for intelligent systems. The authors propose an integrated system approach which measures perceptual and cognitive operator states.

Emotional intelligence. Recognition of affective states focuses on their physical form (e.g., blinking or face distortions underlying human emotions), rather than implicit behavior and function.

Intelligent nonverbal agent. A user model is based on nonverbal information, such as facial expressions, posture, point of gaze, and the speed or force with which a mouse is moved.

Proposed framework.: The methodology integrates nonverbal information with a computational cognitive model of the operator. In turn, this information is fed to the system so that it adapts the interface.

The are four main modules in this framework:

- *Perceptual module.* This module processes images of the face, the eye (gaze location and pupil size), and the upper body, and analyzes their relative motions; the behavioral module processes information about actions applied to the computer interface directly, such as keystroke choices, the strength of keystrokes, and mouse gestures.
- *Behavioral Processing* module. Processes keystroke (choice and rate) and mouse data (clicks and movements).
- *Cognition module*: Reasons possible cognitive states. This model is synchronized with behavioral and perceptual data. All three modules interact with each other.
- *Interface module*. The OMI.

ACT-R is a hybrid architecture to interpret the information from the four modules and adapt accordingly. ACT-R/PM predicts reaction times and contains probabilities of responses of motor movements, shifts of visual attention, and capabilities of human vision. The cognition module builds a detailed mapping of the interpretations of the sensory-motor data onto the ACT-R/PM model.

Conclusions for IASs:

1. Perceptual processing can include lower arm movements, facial data processing, eye-gaze tracking, and mouse gestures. Additional tools are possible, including upper body posture (head and shoulders). Refer to the article for further details on the tools for perceptual processing.
2. The cognitive and emotional states of a person can be correlated with visual features derived from images of the mouth and eye regions.
3. Eye movements can indicate the information an operator is attending to. For instance, eye tracking is a popular online measure of high-level cognitive processing.
4. A cognitive model has the ability to perceive and interact with the external world, as the operator does.
5. ACT-R/PM can *model the effects of fatigue and distraction* on memory, vision, and motor behavior and therefore on performance.
6. Models of cognition could become an important tool for designers of real-time safety-critical systems.

Reference:

Wilson, G.F. and Russell, C.A. (2006). Psychophysiologically versus task determined adaptive aiding accomplishment. Proceedings of the 2nd Augmented Cognition conference, San Francisco, CA.

Overview:

A study was conducted to Investigate two methods of providing adaptive aiding using psychophysiological measures to assess OFS in an uninhabited aerial vehicle (UAV) task.

Methodology

Ten subjects performed the following tasks: monitoring four UAVs, downloading radar images of target areas, designating targets, and giving command to release weapons. Two levels of task demand were used.

Each subject's physiology (five EEG channels, EOG and ECG) was monitored. An artificial neural network was used to determine when they were cognitively overloaded.

Adaptive aiding was provided: (1) only when the psychophysiologically determined OFS indicated high mental workload or; (2) initiated at the first instance of high mental workload that remained on until that task segment ended. The first provided aiding that was turned on and off several times as the OFS varied while in the second the aiding remained on until the task was completed regardless of the changes in physiology.

Results: Both procedures produced statistically significant improvement in performance compared to a "no aiding" condition. The psychophysiologically determined aiding procedure was associated with better performance than the second method but was not significantly better.

Conclusions for IASs:

1. Since psychophysiological measures may be subject to fairly rapid fluctuations, the adaptation could be initiated too rapidly which could interfere with an operator's performance.
2. Real-time analysis of EEG has been used to modify task characteristics to better match operator functional state.
3. In tasks where a wide range of adaptations are available, it will be critical to match the adaptation with the specific cognitive resource.

Reference:

Wilson, G.F., Russell, C.A., and Davis, I. (2006). The importance of determining individual operator capabilities when applying adaptive aiding. Proceedings of the 50th Human Factors and Ergonomics Society Conference, San Francisco, CA.

Overview:

This paper outlines a study to assess the effect of adaptive aiding according to an operator's skill level at varying levels of task difficulty. It was found that the best performance occurred when adaptive aiding was based on psychophysiological data. An artificial neural network was used to implement the adaptation.

Conclusions for IASs:

1. The authors recommend implementing adaptation based on an operator's cognitive abilities and skill levels. The thresholds for initiating adaptation should be based on the cognitive

capabilities of the operator.

2. Aiding is most effectively provided based upon the psychophysiologically determined OFS.

Reference:

Sheridan, T.B., and Parasuraman, R. (2006). Human-automation interaction. In R.S.Nickerson (Ed.). Reviews of Human Factors and Ergonomics, Volume 1. HFES: Santa Monica, CA.

Overview:

This paper reviews recent research in the area of human-automation interaction. It describes taxonomies including supervisory control of automation and function allocation, and models of human-automation interaction. The paper outlines automation-related accidents associated with inadequate feedback and misuse of automation, and evaluates the social, political, and ethical issues related to role of etiquette and trust on operator performance.

Delegation interfaces: In these systems, the operator delegates tasks to the system, at times of the operator's own choosing and receives feedback on their performance.

Conclusions for IASs:

1. *Critical events method.* Automation is triggered by critical events (e.g., when pilot looses consciousness the auto-pilot is automatically executed). Critical events method is flexible as it can be coupled with mission planning but, it does not take into account operator requirements.
2. *Operator performance and physiological measurements.* Automation is adapted based on an assessment of operator state. For instance, this could include using a secondary-task measurement technique, to assess operator workload when performing a primary task, or by using EEG and ERP measurement. Measurement of operator performance or physiological state can be potentially responsive to unpredictable changes in operator cognitive states. Physiological measures can be designed to be relatively unobstrusive, and have high bandwidth compared with performance measures. A disadvantage is measurement sensitivity, which needs to be established in each application domain and is only as good as the technology itself.
3. *Modeling:* A set of pre-defined rules for implementing adaptive automation. Modelling techniques can be implemented offline and easily incorporated into a rule-based expert system. However, a valid model is required and different models within the same system might give contrary decisions at particular moments.
4. *Hybrid:* A mix of the other three methods. Hybrid methods attempt to optimize relative benefits and disadvantages of each technique and may therefore offer the best general approach to implementing adaptive automation.

6.5.1 Cognition Monitor (Cognitive Cockpit, United Kingdom)

The Cognition Monitor module of the United Kingdom's Cognitive Cockpit programme provides a good example of combination-based adaptation (i.e., using a combination of behavioural and physiological measures to infer operator state) (Figure 11).

The COGMON has 32 analogue-to-digital converters capable of recording physiological, behavioural, and situational data in real time. These permit analysis of both low and high frequency electroencephalographic measures. The system can perform near real time analysis of all 32 channels and can examine coherence functions across 10 different frequency bandwidths for each channel. These data provide information about alertness, but also allow inferences to be made about the nature of current cognitive activity.

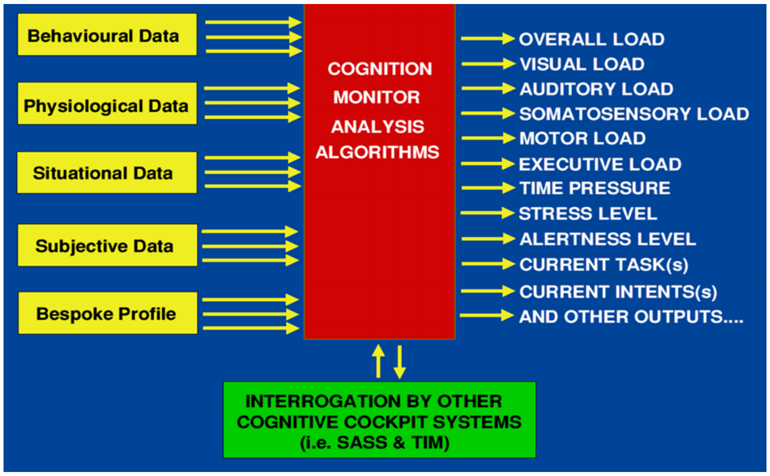


Figure 11: Overview of Cognition Monitor Inputs and Outputs (Willis, 2005).

Blink rate and eye-movement activities (i.e., saccades) are also examined in detail. These provide information about visual workload and can be used to determine the current locus of fixation.

Heart rate and heart rate variability are determined within COGMON. Respiration rate is also measured and analysed. Muscle tonus, a useful measure of alertness and limb activity, is recorded and analysed within COGMON via electromyographic biosensors. Central and peripheral cutaneous temperatures are also measured continuously and electrodermal activity is monitored. These measures provide information about activity levels in the autonomic nervous system (e.g., stress).

Auditory inputs to the operator via headphones are logged by COGMON, as well as general environmental noise. Operator vocalisations are also monitored using microphones and via larynx EMG. Ambient factors including luminance, temperature and noise are also monitored by COGMON.

The COGMON contains a large amount of statistical and analytical software. These algorithms are aimed at performing analysis of COGMON's inputs. They are also designed to process data from different sources *convergently*. Such convergent analyses allow a considerable improvement in inferences about operator state compared to those reliant upon any one source alone. The analytical routines are also aimed at identifying pilot 'bespoke profiles'. Indeed, the philosophy underlying COGMON assumes that the suitability of workload measures may vary from context to context, and from pilot to pilot.

6.6 Summary

Although the COGMON does not claim to be the definitive workload assessment system, it does represent one of the most comprehensive attempts to produce such a system. Common to all such systems, the COGMON is constrained by the maturity and availability of additional hardware and software. For example, reliable optical tracking of visual fixation can considerably enhance the monitor's ability to assess visual workload and determine the current locus of visual attention. In addition, its development is in part, dependent upon the rate of progress made in the other components of the intelligent adaptive system. For example, software aimed at monitoring operator interactions with system controls cannot be fully implemented until the simulation environment is reasonably mature. Similarly, software aimed at the receipt and analysis of general situational data requires that the situation assessment sub-system has reached a sufficient level of maturity. Finally, the complexity of systems such as the COGMON means that its inner functions may be quite hard to visualise making the examination of COGMON's current internal status by the operator extremely difficult. The Cognitive Cockpit programme has explored the use of HTML format (i.e., Internet page based) to represent COGMON states (Figure 12).

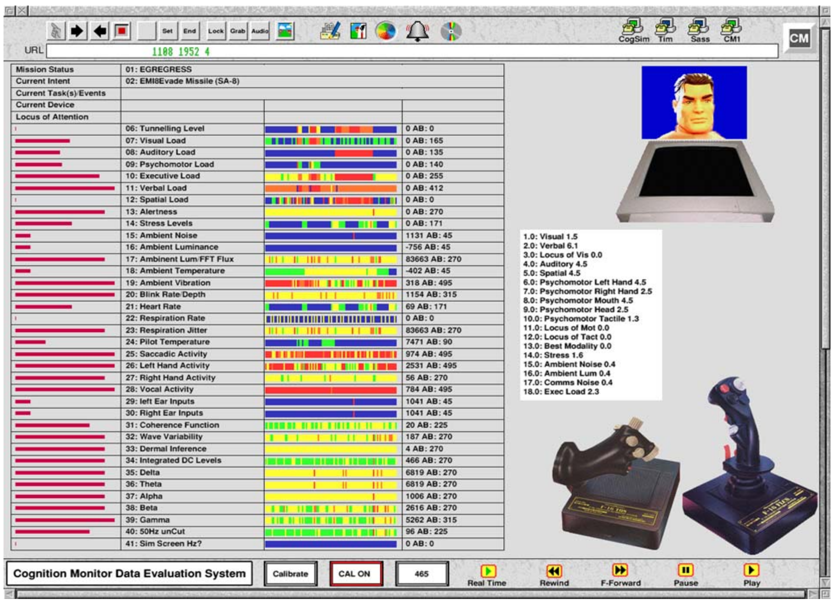


Figure 12: Screenshot of Cognition Monitor visualisation of its internal workings. 41 Inputs are presented on the left, and 18 outputs (i.e., assessment of operator load) are presented on the right (from Willis, 2005).

Table 18 summarises the advantages and disadvantages of the frameworks, and the relationship between the frameworks in terms of authority, agency and user model, and which frameworks are applicable to a given situation (i.e., domain applicability).

Table 18: Summary of adaptation methods.

	Psychophysiological-based Adaptation	Behaviour-based Adaptation	Combination-based Adaptation
Advantages	Can understand how the brain carries out the complex tasks of everyday life—and not just the simple, artificial tasks of the research laboratory. Measures of brain function can indicate not only when an operator is overloaded, drowsy, or fatigued, but also which brain networks and circuits may be affected. Analysis of learning a complex task can be done by understanding the brain changes that accompany stages of learning could lead to the development of better training procedures. The operator's psychophysiology and their performance can be monitored continuously with little intrusion. Can detect changes in cognitive states in real-time. Physiological measures can be designed to be relatively unobtrusive, and have high bandwidth compared with performance measures.	Implicit behavioural measurements are non-intrusive. Plan generation and recognition and intent estimation (e.g., operator intent) can be used to adapt the system based on operator behaviour in combination with a goal/task model. Algorithms based on a-priori probabilities for possible hypotheses have proven useful for recognizing and estimating operator intent. The probabilities can be modified with respect to operator actions.	When behavioural measures are coupled with psychophysiological measures, changes in performance may be more precisely localized to central processing stages than to response-related processing. Measures of brain function may provide more information when coupled with behavioural measures than behavioural measures alone. Measurement of operator performance and physiological state has the advantage of being potentially responsive to unpredictable changes in human operator cognitive states.
Disadvantages	Technology is still immature to make psychophysiological measures applicable outside the laboratory. The classification of operator functional state must be highly accurate in order to provide useful information and also to gain operator acceptance. Higher potential for noise interference.	The "invisibility" of behaviourally-based measures can increase OOTL performance problems and decreases situational awareness. Is dependent on the operator model (i.e., task based)	Is dependent on the user model (i.e., task based). Need to ensure that both types of measures are match and correlate.

	Psychophysiological-based Adaptation	Behaviour-based Adaptation	Combination-based Adaptation
	Psychophysiological measures may be subject to fairly rapid fluctuations. Measurement sensitivity is only as good as the technology itself. Also dependent on the user model (psychophysiological).		
Relationship to Frameworks		Personal Web Server; Stock Trader; DRDC UAV Project; DIAManD; Adaptive Icon; ConCall; Intelligent Classroom; CAMMA	COGPIT, PA/RPA

7 Guidance for the Design of Intelligent Adaptive Systems

7.1 Introduction

The information gathered during the literature review activities about theoretical frameworks, analytical approaches, multi-agent systems, and the use of psychophysiological- and behaviour-based feedback systems provide guidance for the design and development of an IAS. This report has highlighted the strengths and weaknesses of several design and analysis approaches. The objective of this section is to outline and describe a development route-map for the successful development of an IAS; the development process is outlined in Figure 14. The first step is to conduct a taxonomic analysis of the proposed system, followed by the selection of the appropriate framework, analysis methodology, and design methodology. The final step is the selection of the appropriate design guidelines (in terms of principles of adaptation, interaction, etc.). Sections 12.2 through 12.7 describe each step in more detail, with particular emphasis on the selection of the most appropriate method for the development of a specific IAS.

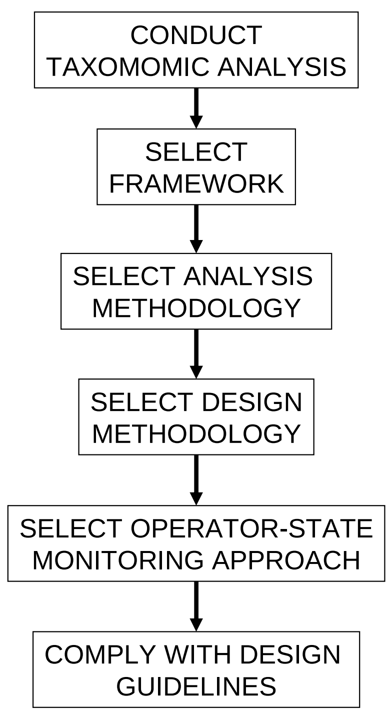


Figure 13: Development route-map for Intelligent Adaptive Systems.

7.2 Conduct Taxonomic Analysis of Proposed Intelligent Adaptive System

The development and implementation of intelligent adaptive systems can be guided by a taxonomic approach that scopes the options available for the capability and functionality of the system. In addition, a taxonomic approach can assist the creation of an audit trail for the design of the system. Finally, it provides a road-map for development in that it allows the development team to focus on specific implementations after scoping all of the possibilities. Figure 14 describes a taxonomic analysis of an intelligent adaptive system for military fast-jet ground attack operations. There are three axes: what mission-related cockpit tasks are appropriate for machine assistance, the degree of such assistance, and the cockpit interfaces through which this interaction is likely to occur.

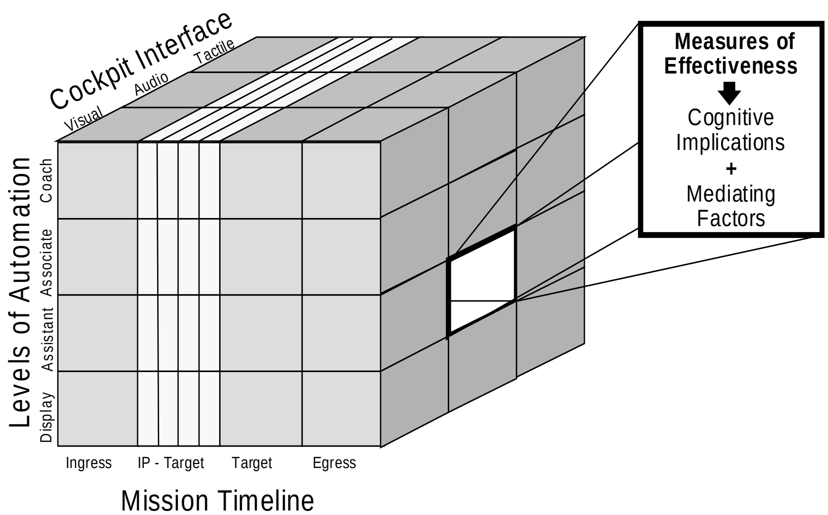


Figure 14: Example of taxonomic analysis of an intelligent adaptive system (from Banbury, 1999).

In order to create such a taxonomy, the following factors need to be defined:

- The role of the human operator;
- The role of the decision aid;
- The level of automation possible;
- The number of behavioural and cognitive functions possible;
- The operational requirements of the scenario in which both the human and decision aid were expected to operate in; and,
- The cockpit interface technologies through which this interaction can occur.

In defining these factors, the approach allows responsibilities to be allocated between the human and automated system, for a given mission segment, and through a specific interface technology. The approach also allows the development team to construct an appropriate mission scenario which encompasses the range of system functionality and capability identified by the taxomony. The mission scenario is used in both the subsequent analysis (i.e., as a precursor to the functional decomposition of tasks, goals and/or functions) and verification (i.e., determination of measures of effectiveness and performance) activities. Finally, the taxomic approach allows the development team to quickly scope the functionality and capability of the IAS in terms priority and feasibility. This allows the development team to maximise the impact of the IAS on operational performance whilst reducing development risk (e.g., due to dependence on immature technology) within the time and budgetary constraints of the project.

7.3 Select Development Framework

The selection of an appropriate development framework affords the development team a number of advantages: reduction in development time and costs from leveraging previous research; benefit from the lessons learnt from past projects; and providing an insight into the potential operational impact of the developed system. One of the most recent and comprehensive attempts to generate a design and development framework for IASs was by Edwards (2004, see 9.3.3 of the report). Edwards examined a variety of theoretical approaches to generate a generic, integrated and comprehensive framework for the development of an intelligent, adaptive, agent-based system for UAV/UCAV control. The generic framework comprised the following design approaches:

- *CommonKADS (and MAS-CommonKADS)*. A knowledge management and engineering methodology that has been used in the development of knowledge-based systems (Schreiber, Akkermans, Anjewierden, de Hoog, Shadbolt, Van de Velde and Wielinga, 2000);
- *IDEF Standards*. A set of guidelines similar to CommonKADS, except that the guidelines support temporal modeling and ontology construction more effectively. IDEF (ICAM Definition) was developed as a product from the US Air Force Integrated Computer Aided Manufacturing (ICAM) project;
- *Explicit Models Design*. The methodology guides the construction of models that identify and compartmentalise the knowledge required by knowledge-based systems. Explicit Models Design has the potential to influence how the intelligent adaptive system functions;
- *Perceptual Control Theory*. Developed by Powers (1990 a &b), and subsequently by Hendy, Beevis, Lichacz and Edwards (2002), the theory provides a feedback control system for the goal-directed behaviour of the knowledge-based system. Similar to Explicit Models Design, Perceptual Control Theory has the potential to influence system functioning; and,
- *Ecological Interface Design*. Developed by Vicente and Rasmussen (1992), Ecological Interface Design provides a set of techniques for the design of the OMI based on levels of cognitive control (i.e., skill, rule and knowledge-based control).

Edwards argues that the combination of these multi-disciplinary approaches provides a comprehensive and efficient means of developing intelligent adaptive systems. The output of these processes is the construction and specification of a number of models that are used to construct the intelligent adaptive system:

- *Organisation Model*. Constructed using CommonKADS, the model incorporates knowledge relating to the organisational context that the knowledge-based system is intended to operate in (e.g., command and control structures, ISTAR etc.);
- *Task Model.* Constructed using a combination of CommonKADS (for high level tasks and functions), and Ecological Interface Design and Explicit Models Design (for greater decomposition of tasks and functions); the model incorporates knowledge relating to the tasks and functions undertaken by all agents, including the operator;
- *Agent Model*. Constructed using CommonKADS, the model incorporates knowledge relating to the participants of the system (i.e., computer and human agents), as well as their roles and responsibilities;
- *User Model.* Developed using Explicit Models Design, the model incorporates knowledge of a human operator's abilities, needs and preferences;
- *System Model*. Specified using Explicit Models Design, the model incorporates knowledge of the system's abilities, needs, and the means by which it can assist the human operator (e.g., advice, automation, interface adaptation);
- *World Model.* Specified using Explicit Models Design, the model incorporates knowledge of the external world, such as physical (e.g., principles of flight controls), psychological (e.g., principles of human behaviour under stress), or cultural (e.g., rules associated with tactics adopted by hostile forces);
- *Dialogue/Communication Model*. Specified using a combination of CommonKADS and Explicit Models Design, the model incorporates knowledge of the manner in which communication takes place between the human operator and the system, and between the system agents themselves;
- *Knowledge Model*. Specified using CommonKADS, the model incorporates a detailed record of the knowledge required to perform the tasks that the system will be performing; and,
- *Design Model*. Created using CommonKADS, the model comprises the hardware and software requirements related to the construction of the intelligent adaptive system. This model will also specify the means by which operator state is monitored.

Figure 16 illustrates the sequential process by which the models described above are created. It also indicates where there are duplications of the models; the three task models and two communication models can both be combined. The generic framework posited by Edwards shares many similarities to the other frameworks described in Section 9.3.3, most notably the Cognitive Cockpit, which also borrowed heavily from both the CommonKADS and Ecological Interface Design approaches. Common to all approaches reviewed in this document are following system functions:

- Tracking of operator goals/plans/intent (and progress towards them);
- Monitoring of operator state;

- Monitoring of world state;
- Knowledge of the effects of system advice, automation and/or adaptation on operator and world state (i.e., closed-loop feedback); and,
- Bespoke OMI to handle the interaction/dialogue between the operator and the system agents (e.g., tasking interface manager).

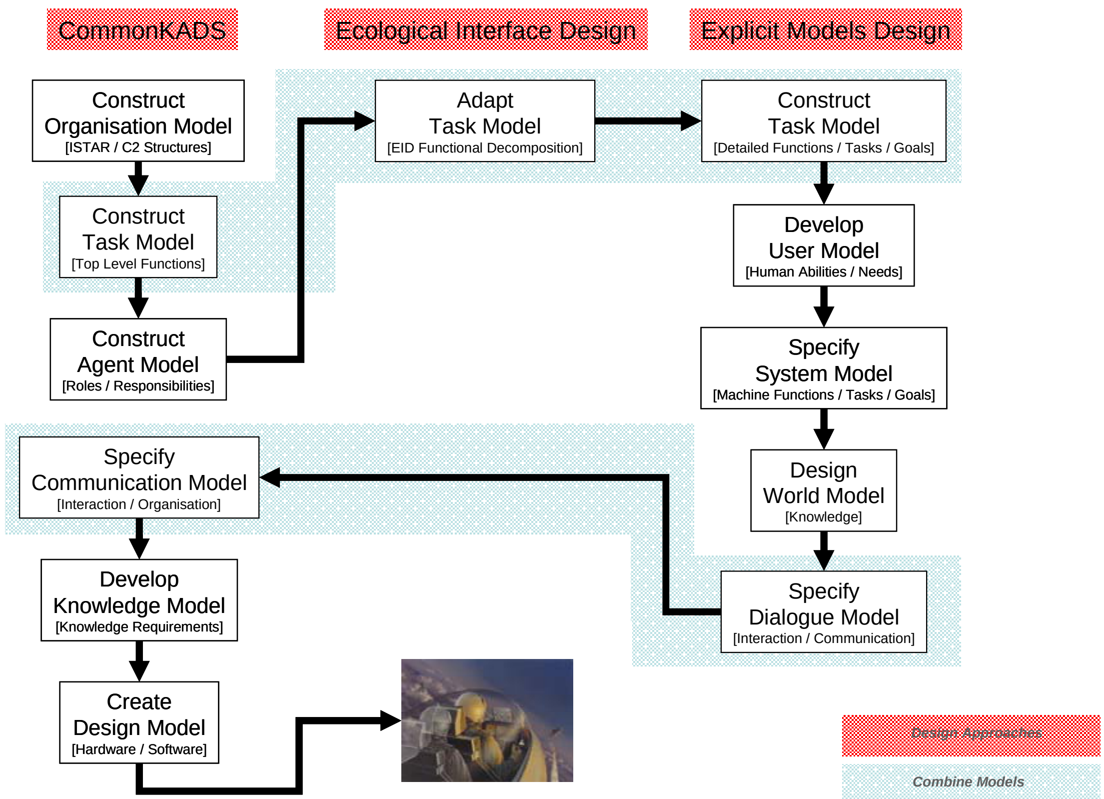


Figure 15: Generic development framework for Intelligent Adaptive Systems (Edwards, 2004).

Furthermore, the models described can also be mapped on to the generic conceptual architecture previously described in Section 8.5.1. Figure 16 illustrates the mapping of Edward's generic development framework to the generic conceptual architecture: the User Model enables the physiological monitoring of the operator; the Task, System and World Models enable the monitoring of mission plan/goal completion, task/activities, as well as entities and objects in the external environment; the Knowledge Model enables the system to provide advice to the operator, automate tasks, or adapt the OMI; and the Dialogue Model enables the means of interaction between the system and the operator.

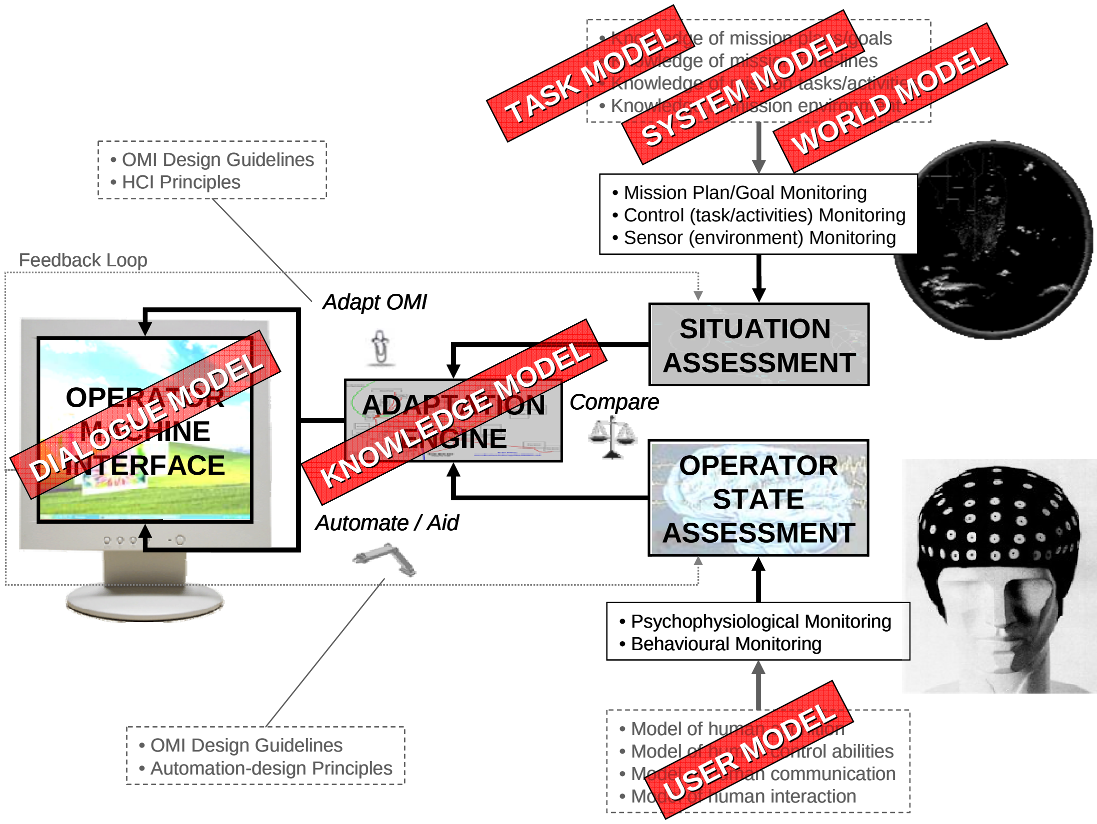


Figure 16: Mapping of Edward's framework to generic conceptual architecture.

Figure 17 provides advice for the selection of specific frameworks that may be used to guide the development process for a particular target domain (e.g., lessons learnt, appraisal of technological maturity). Frameworks are divided into two categories, reflecting the two streams of development by the HCI and HF communities:

- *Civilian*. Personal computer-based applications and web-based applications; and,
- *Military*. Error-critical applications (e.g., for the control of UAVs and piloting of combat aircraft).

Military-based frameworks tend to be used more for complex and error-critical applications. In this case, civilian aviation applications are also included (e.g., CASSY). Finally, both framework categories are broken down further into:

- *Task Execution*. Automation technologies that perform specific tasks for the operator (in blue); and,
- *Information Management*. Decision support and/or adaptive interface technologies that assist the operator manage information (in red).

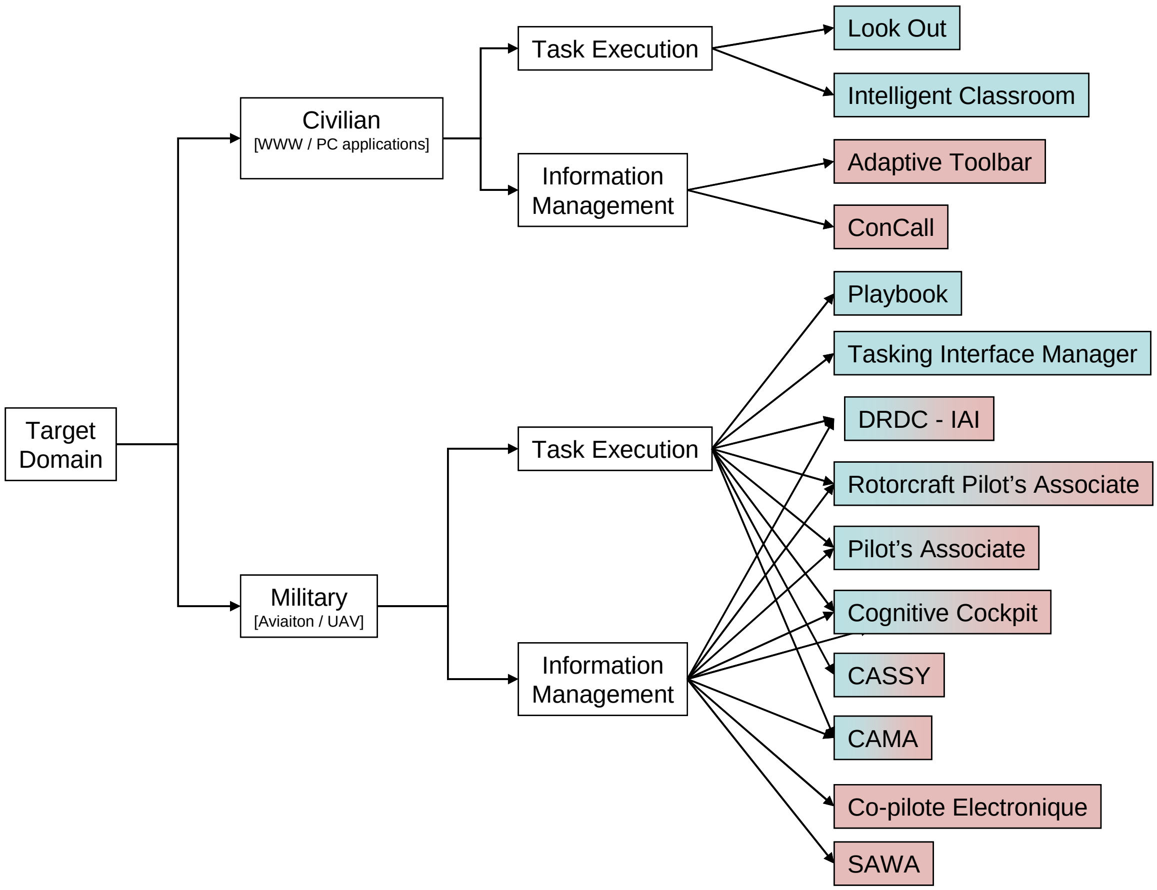


Figure 17: Decision tree for selection of design frameworks.

7.4 Select Analysis Methodology

Analysis methodologies provide the OMI communication, visual display and control requirements needed for the design of the IAS, as well as a functional decomposition of the tasks within the domain envisaged for it. The results of this analysis are used to populate the models described in section 12.3. Figure 18 associates each of these models with the relevant tools/methods/techniques previously described in this report.

Specifically:

- *Cognitive Analysis Methodologies*. Contribute to the construction of the Task, Agent and User Models (Section 9.2);
- *Task Analysis Methodologies.* Contribute to the construction of the Task, Agent and System and World Models (Section 9.2);

- *Human-Machine Function Allocation and Agent-based Design Principles*. Contribute to the construction of the Agent, Dialogue and Communication Models (Section 10.2.2);
- *Human-Machine Interaction and Organisation Principles*. Contribute to the construction of the Dialogue and Communication Models (Section 10.2.2);
- *IDEF5 Guidelines*. Contribute to the construction of the ontology and knowledge base. This is then used to enumerate the knowledge captured by the analysis process (Section 8.4.4);
- *Domain Feasibility, Cost-Benefit Analysis and Principles for Closed-Loop Implementation*. Contribute to the construction of the Design Model, which includes the means by which operator state is monitored (Section 11); and,
- *Human Factors and Human Computer Interaction Principles.* Contribute to the construction of the OMI and related systems (Section 10.2). The design process might also include principles from Ecological Interface Design (Section 9.3.4).

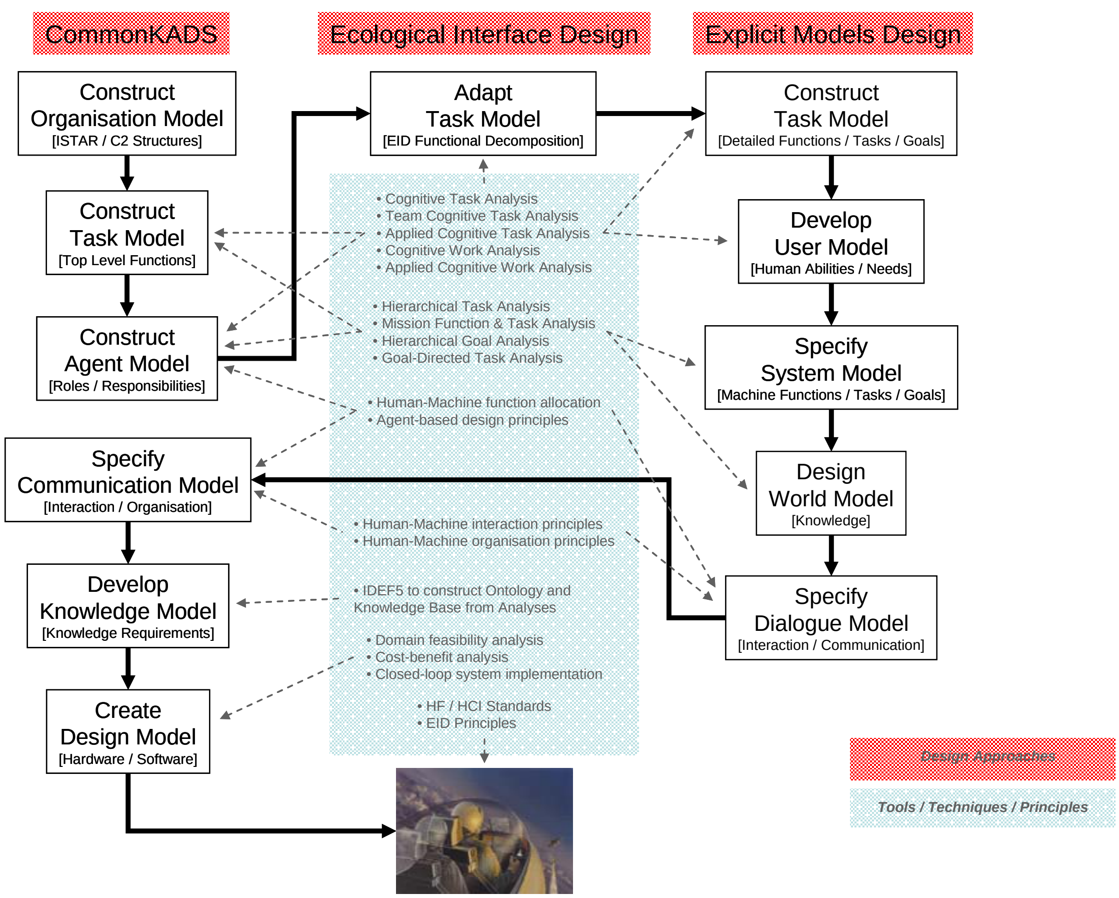


Figure 18: Analysis techniques mapped on to Edward's generic framework.

Figure 20 provides advice for the selection of analysis methodologies based upon project constraints that may be used to guide the development process (e.g., lessons learnt, validation studies). All constraints should be considered as a whole, and in practice, it is likely that compromises amongst the constraints will be required. Project constraints are described in terms of:

- *Budget*. The conduct of the analysis is cost efficient and time consuming;
- *Tasks for Analysis.* Types of tasks that need to be analysed. Methodologies are sub-divided into those that are best to suited to analyse *Simple*, *Complex* and *Cognitive* (e.g., involving processes such as decision making and problem solving) tasks; and,
- *Analysts*. Project personnel that will be required to conduct the analysis. Methodologies are sub-divided into those that are *Simple to Learn and Apply* and those that are *Difficult to Learn and Apply*.

Figure 19 also illustrates that the analysis methodologies tend to fall into two distinct categories; those that can be used for complex tasks, but are time-consuming and require well-trained analysts (in red), and those that can be used for simple tasks, in less time and with lesser-trained analysts (in blue).

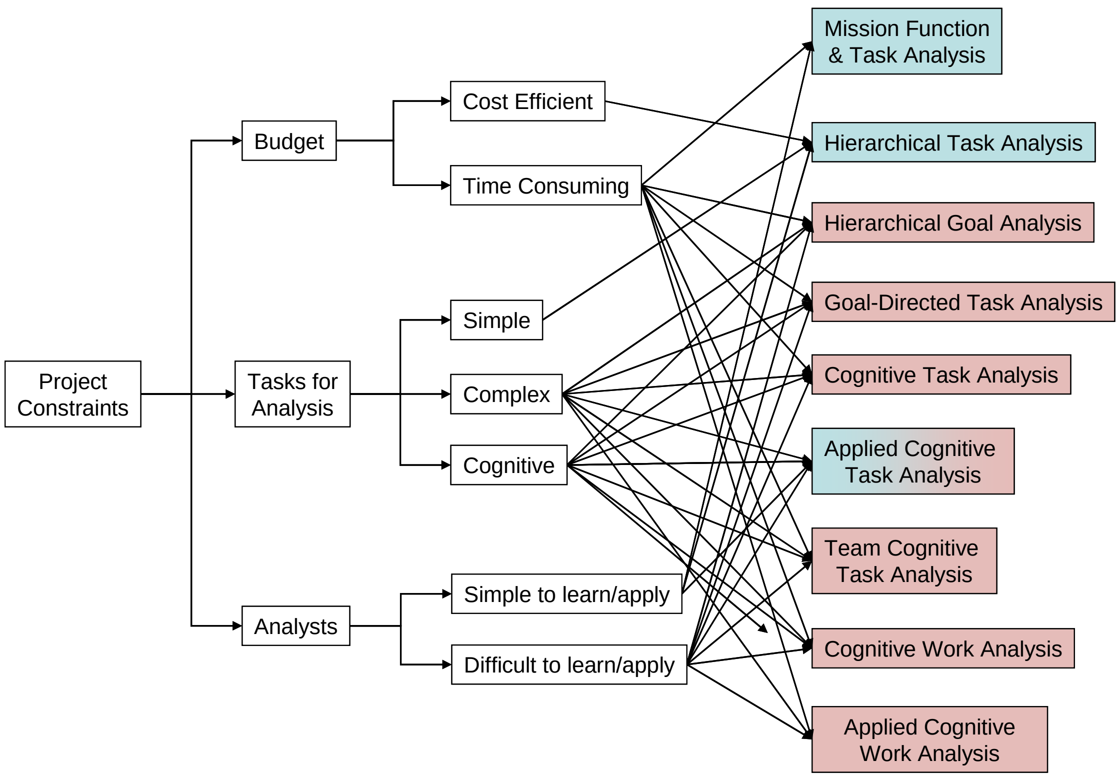


Figure 19: Decision tree for selection of analysis techniques.

7.5 Select Design Methodology

Figure 20 provides advice for the selection of design methodologies that may be used to guide the development process of a particular target system (e.g., lessons learnt, validation studies). All requirements should be considered together. Design methodologies are described in terms of:

- *Multi-Agent Requirements*. Related to the complexity of the system, this is the requirement for the system to utilise multiple software agents;
- *Feedback Requirements*. The requirement for a closed-loop system (i.e., the ability of the system to resample operator and world state following the implementation of adaptation);
- *System Complexity*. The degree to which the system is expected to assist the operator in a range of tasks;
- *Cognitive Requirements*. The degree to which the system is expected to support the operator in cognitive-related tasks (e.g., decision making and problem solving); and,
- *Safety/Reliability Requirements*. The requirement that the system is expected to support the operator in error/reliability-critical tasks (e.g., aviation, military).

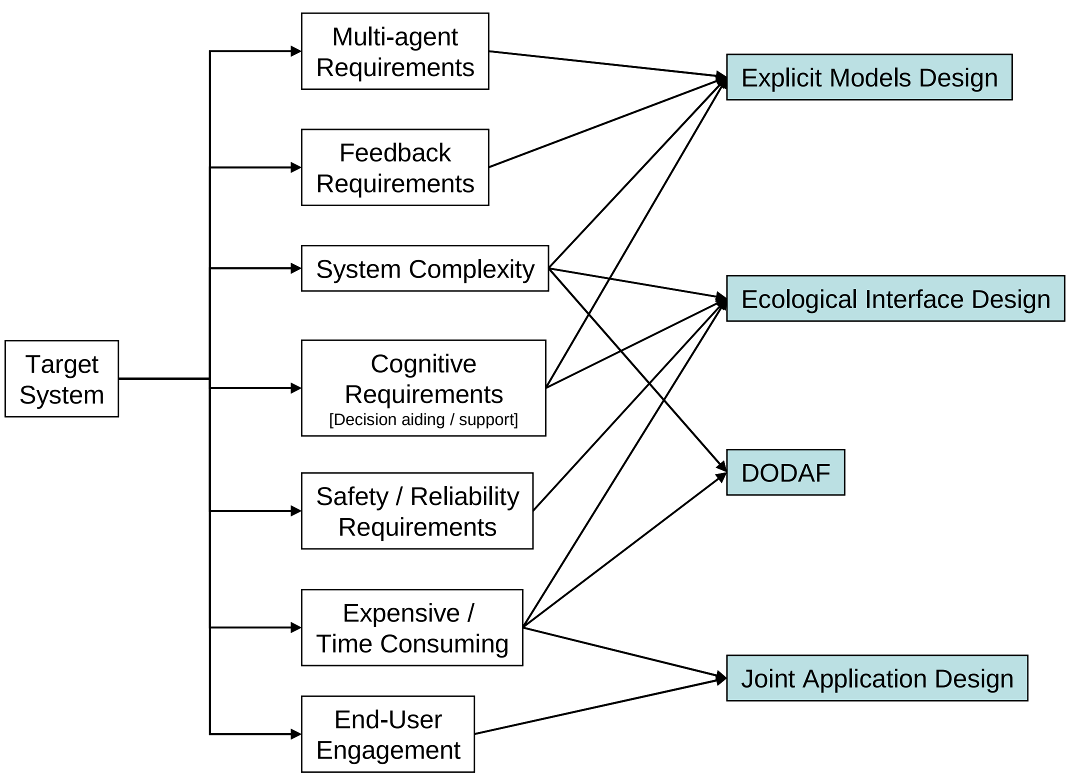


Figure 20: Decision tree for selection of design methodologies.

- *Expensive/Time Consuming*. The conduct of the design methodology is expensive and time consuming; and,
- *End-Operator Engagement*. The requirement that potential end-operators of the system are expected to take part in the design and development process.

7.6 Select Operator-State Monitoring Approach

Figure 21 provides advice for the selection of an operator-state monitoring approach that may also be used to guide the development process of the target system (e.g., lessons learnt, appraisal of technological maturity). All requirements should be considered together Operator-state monitoring approaches are described in terms of:

- *Handling Unpredictable Events*. The requirement for the system to assess operator state for unpredictable events (i.e., outside of ‘normal’ operations);
- *Detect Implicit Behaviours*. The requirement for the system to monitor operator state despite little or no observable actions by the operator (e.g., cognitive activities);
- *Real-time Monitoring*. The requirement to determine operator state in real-time (e.g., aviation-related applications);
- *Non-intrusive Monitoring*. The requirement that the operator is not aware of or impeded by the monitoring system;
- *Detect Explicit Behaviours*. The requirement for the system to monitor operator state through observable actions by the operator (e.g., using vehicle controls);
- *Intent Monitoring*. The requirement for the system to determine the operator’s intent (e.g., goals and objectives);
- *Precision*. The requirement for the system to determine operator state with fine-grained precision, as opposed to determining whether the operator is merely over-loaded or under-loaded;
- *Mature Technology*. Related to the expected timing of the field-ability of the system, the degree to which the technology is mature (i.e., ready to be fielded) or is in development;
- *User Model.* The requirement for the system to have a highly accurate, or even bespoke, user model (e.g., model of human cognition, abilities etc.); and,
- *Immune to Noise Interference*. The requirement that the system is immune to electrical-magnetic noise interference (e.g., EEG monitoring is very susceptible to this kind of interference and as a result makes it deployment in aircraft very difficult).

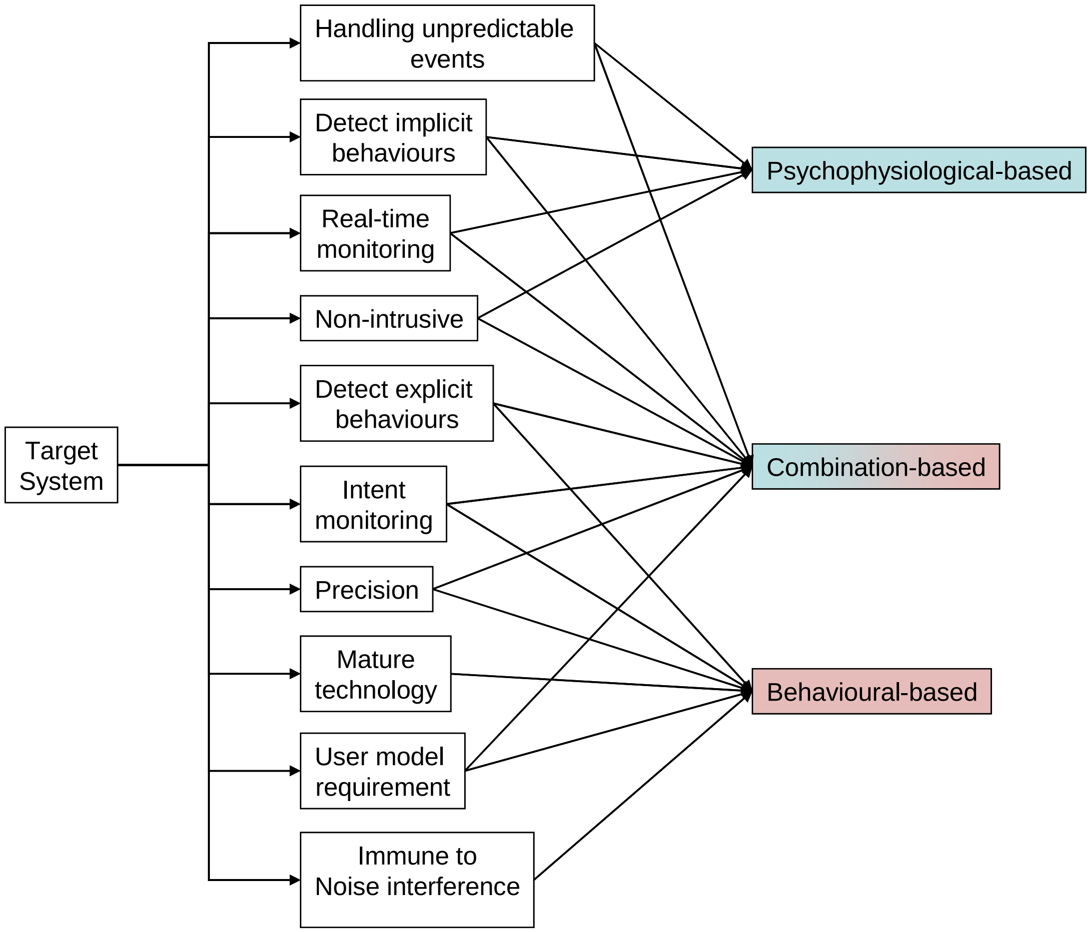


Figure 21: Decision tree for selection of operator-state monitoring approaches.

7.7 Comply with Design Guidelines

The final step for developers is to consider and address a number of design guidelines before an IAS can be effectively deployed into service. The design guidance outlined in Section 11 provides guidance relating to human-agent teamwork and organisation, as well as general aspects of the OMI (the means by which the operator interacts with the systems agents). As an example, the Tasking Interface Manager of the Cognitive Cockpit is described.

General OMI design guidance can also be found in the report “Development of Decision Aid Implementation Guidance for the INCOMMANDS Human Factors Design and Evaluation Guide” (Banbury and Gauthier, 2007). The aim of this document was to support the design and development of OMI concepts developed as part of the INCOMMANDS TDP by providing a structured and comprehensive set of design guidelines which address electronic support systems concepts. The document is comprised of guidance relating to OMI design goals as well as specific guidance relating to specific classes of electronic support systems, including: Information Management Aids (guidelines to optimise and organise the information presented for efficient information acquisition and synthesis); Decision Making Aids (guidelines to support efficient and effective decision making); and Control and Action Aids (guidelines to minimise operator out-of-the-loop problems). Finally, the report provides guidelines relating to Design and Evaluation, and Training and Implementation.

7.8 Summary

The previous sections have identified a number of criteria that can be used to determine which of the analysis and design frameworks and methodologies should be used for the design and development of a specific intelligent adaptive system. In general, most of the frameworks and methodologies are relatively generic (i.e., context independent) and scalable (i.e., adaptable for a particular application). In addition, approaches can be combined to capitalise on their unique strengths, whilst mitigating their weaknesses. The selection of these frameworks and methodologies can therefore be reasonably flexible, which is fortunate given that there are a number of other constraints that might have a greater impact on the selection of approaches. These constraints include:

1. *Project Constraints.* Constraints related to the procurement or research project, including schedule, in-service timescales, budget, and availability of analysts (and their level of expertise);
2. *Target Domain Constraints.* Constraints related to the target domain of the to-be-developed system, such as complexity, criticality, uncertainty, and environmental constraints (e.g., especially relevant to the choice of operator state monitoring systems);
3. *Operator Constraints.* Constraints related to the operator, including consequences of error and overload, what support is needed, how much support is needed, and who needs to be in control (e.g., especially relevant in combat domains); and,
4. *Task Constraints.* Determination of the task conditions under which a particular IAS may be beneficial, what tasks are suitable for support by an IAS, and under what conditions are these technologies appropriate (e.g., suitable for goal and/or operator state monitoring, triggering conditions). Finally, determine those tasks where IAS support will, in the opinion of the operator, be most beneficial, and thus enhance the likelihood of operator acceptance.

Section 12.8.1 illustrates the complete process using a worked example of the Intelligent Classroom IAH system.

7.8.1 Worked Example: Intelligent Classroom

Taxonomic Analysis: The role of the machine is to dynamically assist the human lecturer (operator) in a classroom environment (controls camera, automatic slide-switcher). The role of the human operator is to simply present a lecture. The level of automation is determined by watching and observing the operator’s behaviours and recognizing, projecting and executing some plan to accomplish an operator goal (i.e., match the operator’s actions to a set of known plans and execute that plan to achieve some goal). The operator, in executing part of the plan, expects the machine to do its part of the plan and sets the operational requirements of the scenario in which both the human and the machine were expected to operate in. The interaction between the operator and the machine does not occur through an OMI, but rather through a camera that monitors and keeps track of the various activities pursued by the human operator which is goal-based and driven by task recognition.

Select Development Framework: The Intelligent Classroom is a civilian program that executes a task normally performed by a human operator. The resulting framework for the Intelligent Classroom requires three models including Task, System and World Models that will enable the monitoring of mission plan/goal completion, task/activities, as well as entities and objects in the external environment.

Select Analysis Methodology: Figure 20 outlines a selection process of analysis methodologies based upon the project constraints that can guide the development process of the Intelligent Classroom. In the case of the Intelligent Classroom, the tasks are relatively complex and require some cognitive analysis. Therefore, goal-directed and applied cognitive task analyses would be the most appropriate analyses to use. The budget and the analysts assigned to perform the analysis will determine the depth and breadth of the approaches.

Select a Design Methodology: Figure 21 guides the development process of a particular target system in terms of multi-agent requirements, feedback requirements, system complexity, cognitive requirements, and safety/reliability requirements. The Intelligent Classroom is a relatively complex system that requires reliable multiple agents to monitor, recognize and execute some plan (action). Feedback and cognitive requirements are not important for the development of this system since it is obvious when an action has been performed (i.e., change presentation slide). Ecological Interface Design and Explicit Model Design appear to be the most appropriate design methodologies to guide the development process of the system.

Monitor Operator State: To adapt the system dynamically, operator actions and inputs, in terms of gestures and voice recognition must be monitored. In this case, the operator-state that must be identified is the operator's actions in the context of what the system believes the operator is doing. To accomplish this, the system must handle unpredictable events, monitor the operator state in real-time, be non-intrusive, detect explicit behaviours and monitor the operator intent. Therefore, using a behaviour-based approach to monitor operator state is considered the most appropriate approach.

8 Conclusions

8.1 Summary

Research pertaining to IASs has demonstrated that when automation and interface adaptation that are implemented dynamically and intelligently (i.e., in response to changing task demands placed upon the operator), can permit the chief benefits of automation (e.g., workload regulation) to be realised without most of the drawbacks associated with conventional or static automation (e.g., loss of Situation Awareness). One of the chief assumptions underlying the use of IASs in many of the domains covered by this review is that an operator can control a process during periods of moderate workload and hand-off control of particular tasks when workload either rises above, or falls below, an optimal level. Specific task demands can be selected and modified to ensure that the most critical tasks are attended by the operator, and an optimal level of workload is maintained. Intelligent Adaptive Systems are also sensitive to mission context, in that they adapt to both operator and mission/goal requirements.

The literature research obtained during this project achieved the following goals:

- Identify the advantages, disadvantages and applicability of development frameworks, analysis methodologies, design approaches, and operator-state monitoring approaches;
- Make some progress in unifying the hitherto independent HF and HCI approaches to the development of IASs by providing a generic conceptual framework (i.e., R-A-A: role, agency and authority) and a generic conceptual architecture which map to both approaches by focusing on system functionality and capability; and,
- Develop guidance for developers to assist in the successful design, development and implementation of IASs.

8.2 The Way Ahead

Several technologies were once major stumbling blocks to exploiting IAS concepts. However, interest in these technologies external from the military domain has allowed these technologies to reach maturity. These technologies can be summarised as follows (Geddes and Shalin, 1997):

- Increases in computing power and associated technologies;
- Development of object-oriented computer languages that are especially suited to support intelligent aiding systems because of their use of abstraction;
- Continued progress in Artificial Intelligence has provided a large number of mature reasoning algorithms and operational knowledge representations;
- Knowledge capture methods are well developed for dealing with multiple knowledge sources and tacit knowledge; and,

- Architectures for large-scale intelligent systems have been developed that support a distributed, co-operative environment.

The evaluation of IASs is a controversial endeavour. Much of the past empirical research on evaluating such systems has drawn on techniques and models from experimental psychology. These experimental techniques tend to reflect the evaluation of attributes of large populations when confronted with frequently recurring treatments. However, Geddes and Shalin (1997) view this approach as inappropriate for IASs, in which the total population of operators is normally small, and the significant stimuli are rare. Geddes and Shalin suggest that the mismatch between evaluation methods and the nature of IASs has resulted in many experimental evaluations failing to detect any significant performance differences between aided and unaided conditions. Yet, subjectively, the operators report strong reactions to the aids, both favourable and unfavourable. The authors argue that unless evaluation methods are developed and accepted by the development community, there is a risk that progress towards successful IASs will be constrained by an apparent lack of value.

The potential benefits to successful implementation of IAS are high; potential benefits include a reduction in accidents and incidents, greater economic efficiency and reliability of systems and operations, and greater combat effectiveness of military operations. However, the potential difficulties of applying IASs to military and civilian domains are also significant. The inclusion of new IAS technologies does not reduce the need for Human Factors input but simply redirects it. Consideration of the human element within the system is essential to the design and development of IASs, in order to ensure that incidents and accidents are mitigated, and the expected benefits to safety and mission effectiveness are realised.

Finally, despite the synergy between research within the fields of Human Factors and Human-Computer Interaction, there is a pressing practical need for these two research domains to exploit the lessons learnt and leverage research findings from each other. Efforts towards these goals should prove extremely fruitful.

9 Acronyms

AA	Adaptive Automation
ACTA	Applied Cognitive Task Analysis
ACT-R	Adaptive Control of Thought-Rational
ACT-R/PM	Adaptive Control of Thought-Rational/Perceptual Motor
ACWA	Applied Cognitive Work Analysis
AI	Artificial Intelligence
ANS	Autonomic Nervous System
ARP	Applied Research Package
ARP	Applied Research Program
AST	Associate System Technology
ATM	Air Traffic Management
AugCog	Augmented Cognition
AUI	Adaptive User Interface
AWW	Anti-Air Warfare
BAe	British Aerospace
C3I	Command, Control, Communication and Intelligence
CADM	Core Architecture Data Model
CAMMA	Crew Assistant Military Aircraft
CASSY	Cockpit Assistant System
CDAS	Cognitive Decision Aiding System
CE	Co-Pilote Electronique
CHI	Computer-Human Interaction
CIE	Crew Intent Estimation
CM	Cognition Monitor
CPU	Central Processing Unit
COGMON	Cognitive Monitor
COGPIT	Cognitive Cogpit

ConTA	Control Task Analysis
CSE	Cognitive System Engineering
CTA	Cognitive Task Analysis
CWA	Cognitive Work Analysis
DAI	Dynamically Adaptive Interface
DAT	Decision Aiding Taxonomy
DBMS	Data Base Management System
DERA	Defence Evaluation and Research Agency
DIAManD	Decision-theoretic InterAction Manager for Discourse
DGMS	Dialogue Generation and Management System
DoDAF	US Department of Defence Architectural Framework
DRDC	Defence Research and Development Canada
DSS	Decision Support Systems
DTM	Data Transfer Module
ECG	ElectroCardioGram
EEG	Electroencephalography
EMD	Explicit Models Design
EMF	Electro-Magnetic Frequency
EMG	ElectroMyoGraphic
EID	Ecological Interface Design
EOB	Electronic Order of Battle
EOF	Electro-OculoGraphic
ERN	Error-Related Negativity
ESS	Electronic Support Systems
ESSM	Electronic Sensor Surveillance Measure
ERPs	Event-Related Potentials (ERP)s
FAN	Functional Abstraction Network
FCBA	Future Carrier-Borne Aircraft
fMRI	functional Magnetic Resonance Imaging
FOAEW	Future Organic Airborne Early Warning

FOAS	Future Offensive Air System
FOAS	Future Offensive Air System
GIM	Global Implicit Measures (of Situational Awareness)
GOMS	Goals, Operators, Methods, Selection rules
GSR	Galvanic Skin Response
GTA	Goal Directed Task Analysis
GUI	Graphical User Interface
HCD	Human-Centered Design
HCI	Human-Computer Interaction
HEC	Human Electronic Crewmember
HMI	Human-Machine Interface
HF	Human Factors
HFM	Human Factors and Medicine
HGA	Hierarchical goal analysis (HGA)
HOTAS	Hands On Throttle And Stick
HTA	Hierarchical Task Analysis
IAA	Intelligent Adaptive Automation
IAH	Intelligent Adaptive Hybrid
IAI	Intelligent Adaptive Interfaces
IAS	Intelligent Adaptive System
ICF	Intelligent Control Framework
IOOD	Intelligent Object-Oriented Design
IP	Information Processing
IPSS	Integrated Passive Sensor System
ISU	In-Service Update
JAD	Joint Application Design / Development
KA	Knowledge Acquisition
KBS	Knowledge Based System
LAP	Low Altitude flight Planner
LSPA	Learning System, Pilot Aiding
MBMS	Model Based Management System

MEG	MagnetoEncephaloGraphy
MFTA	Multi Function Task Analysis
MiDAS	Mission Displays for Autonomous Systems
MoD	Ministry of Defence
MOE	Measures of Effectiveness
MRI	Magnetic Resonance Imaging
OFS	Operator Functional State
OMI	Operator Machine Interface
OODA	Observe Orient Decide Act
OV	Operations View
OWL	Web Ontology Language
PA	Pilot’s Associate
PACT	Pilot Authorizing and Control Tasks
PCT	Perceptual Control Theory
PET	Positron emission tomography
PGG	Plan-Goal Graph
PIER	The Pilot Intent and Error Recognition
PVI	Pilot Vehicle Interface
P-VACS	Playbook-enhanced Variable Autonomy Control System™.
RAA	Roles-Agent-Authority
RAF	Royal Air Force
RPA	Rotorcraft Pilot’s Associate
RPD	Recognition Primed Decisions
RTIC/RTOC	Real Time Into the Cockpit / Real Time Out of the Cockpit
SA	Situation Awareness
SAM	Surface-to-Air Missile
SASS	Situation Assessment Support System
SATCOM	Satellite Communication
SAWA	Situational Awareness Assistant
SM	Sensor Manager

SME	Subject Matter Expert
SOCA	Social Organization and Cooperation Analysis
SV	Systems View
SWRL	Semantic Web Rule Language
TCD	Transcranial Doppler sonography
TIBS	Tactical Information Broadcast Service
TIM	Tasking Interface Manager
TMS	Transcranial Magnetic Stimulation
TSI	Tactical Situation Interpreter
TV	Technical Standards View
UAV	Uninhabited Aerial Vehicle
UCAVs	Uninhabited Combat Air Vehicles
UCD	User-Centered Design
US AFRL	United States Air Force Research Laboratory
USAF	United States Air Force
WCSS	Work-Centered Decision Support
WDA	Work Domain Analysis
WSCE	Weapon System Concept Engineering

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(U) Human−machine system performance can be significantly improved by using technologies that can intelligently adapt the operator machine interface (OMI) and/or task automation provided to the operator in accordance with both the external context (i.e., task environment) and internal context (i.e., operator state). However, a lack of established design guidelines presents a significant challenge to the effective design of Intelligent Adaptive Systems (IASs). An extensive literature review was conducted to examine existing approaches to the design of IASs, and a unified framework was developed to describe these design approaches using consistent and unambiguous terminology. Combining design methodologies from both Human Computer Interaction (HCI) and Human Factors (HF) fields, conceptual and design frameworks were also developed to provide guidelines for the design and implementation of IASs. Finally, a number of criteria that can be used to select appropriate analytical techniques and design approaches were also developed. The proposed frameworks not only provide guidelines for designing IASs in the military domain, but also guide the design of other generic systems to optimize human−machine system performance.

(U) Il est possible d'améliorer considérablement les performances des ensembles homme−machine en ayant recours à des technologies qui peuvent adapter intelligemment l'interface opérateur−machine (IOM) et/ou l'automatisation des tâches et le soutien accordé à l'opérateur conformément au contexte externe (c.−à−d. le contexte de la tâche) et au contexte interne (c.−à−d. l'état de l'opérateur). Toutefois, l'absence de lignes directrices établies en matière de conception constitue un lourd obstacle à la conception efficiente de systèmes adaptatifs intelligents (SAI). Un examen approfondi de la documentation a été effectué afin d'examiner les démarches actuelles en conception des SAI et un cadre de travail unifié a été élaboré afin de décrire des perspectives conceptuelles en faisant appel à une terminologie uniforme et non ambigüe. Par ailleurs, en combinant des méthodes de conception des domaines des interactions homme−ordinateur (IHO) et des facteurs humains (FH), nous avons élaboré des cadres conceptuels et de design afin d'élaborer des lignes d'orientation afin d'aider à la conception et à la mise en oeuvre de SAI. Un certain nombre de critères de sélection des méthodes analytiques et conceptuelles appropriées ont aussi été développés. Les cadres recommandés ne guideront pas seulement la conception des SAI dans les domaines militaires, ils aideront aussi dans le domaine des systèmes civils afin d'optimiser les performances des systèmes homme−machine.

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(U) intelligent adaptive system;interface design;human−machine system;human−machine interaction;operator machine interface;human computer interaction;agent−based system;design framework;analytical method;behaviour−based system;physiological−based system;human automation interaction;adaptive automation